# Tail Risk, Capital Requirements and the Internal Agency Problem in Banks

Nataliya Klimenko *

This version: September, 2014

**Abstract**

This paper shows how to design incentive-based capital requirements that would prevent the bank from *manufacturing tail risk.* In the model, the senior bank manager may have incentives to engage in tail risk. Bank shareholders can prevent the manager from taking on tail risk via the optimal incentive compensation contract. To induce shareholders to implement this contract, capital requirements should internalize its costs. Moreover, bank shareholders must be given incentives to comply with minimum capital requirements by raising new equity and expanding bank assets. Making bank shareholders bear the costs of compliance with capital regulation turns out to be crucial for motivating them to care about risk-management quality in their bank.

**Keywords:** capital requirements, tail risk, moral hazard, asset expansion, incentive compensation

**JEL classification:** G21, G28, G32, G35

**Acknowledgements:** I am grateful to Sumit Agarwal, Mohamed Belhaj, Bruno Biais, Renaud Bourlès, Claire Célérier, Jean-Edouard Colliard, Jean-Paul Décamps, Dominique Henriet, Jeremy Ko, Thomas Mariotti, Erwan Morellec, Bruno Parigi, Guillaume Plantin, Lev Ratnovski, Jean-Charles Rochet, Stephane Villeneuve for helpful suggestions. I thank seminar participants at Toulouse School of Economics, University of Zürich, SFI/EPFL, as well as the audience of 29th International Conference of French Finance Association, III International Finance Conference, EEA/ESEM 2012 Annual Meeting, 62nd Annual Meeting of the French Economic Association, Swiss Finance Institute research days in Gerzensee, 2014 Conference of the Financial Engineering and Banking Society. Financial support from the European Research Council under the European Union's Seventh Framework Program (FP7/2007-2013)/ERC Grant agreement N 249415 is gratefully acknowledged.

*E-mail: nataliya.klimenko@bf.uzh.ch. Address: University of Zürich, Department of Banking and Finance, Plattenstrasse 32, 8032 Zürich. Tel.: +41 44 634 37 81.

# 1 Introduction

One of the main roles of bank capital regulation is to restrain banks from excessive risk-taking in the context of the explicit and implicit government guarantees they may enjoy. However, the experience of the 2007-2009 financial crisis clearly shows that the capital regulation in place failed to perform this role. This failure may be partially attributed to the fact that the capital regulation framework was not adjusted in time to the substantial changes in bank business culture brought about by new techniques in financial engineering. One of the direct results of these changes was the emergence of *tail risk*, characterized by rare but devastating losses. As pointed out by Acharya, Cooley, Richardson and Walter (2010), top management in banks was engaged in manufacturing tail risk in order to generate immediate profits, without regard for the long-term consequences. Recent empirical evidence shows that, to a large extent, such behaviours were caused by the perverse incentives inherent to the existing compensation schemes. Yet, given that incentive compensation is supposed to induce managers to act in shareholders' interests, this might suggest that bank shareholders were largely neglecting the quality of risk management when specifying performance goals.[1]

In this study, I attempt to rethink the design of bank capital regulation, tailoring it to effectively deal with the problem of "manufactured" tail risk in the banking sector. I propose an incentive-based design of capital requirements which would induce shareholders to pay attention to the quality of risk management in their bank and to shape the incentive compensation of a senior bank manager in such a way as to prevent him from engaging in tail-risk strategies. To illustrate these proposals, I build a simple continuous-time model using the principal-agent framework, in which a senior bank manager has a reversible choice between a prudent risk management strategy and imprudent one. The imprudent risk management strategy implies taking on tail risk and provides higher expected asset growth rate than the prudent risk management strategy, thereby allowing the manager to create the illusion of high performance in the short run. In addition, imprudent risk management brings private benefits to the manager,[2] which creates a potential conflict of interests between the manager and bank shareholders, a situation further referred to as the internal agency problem. Since the materialization of tail risk in a single bank may incur negative externalities on the rest of the banking sector, it is assumed that

[1] Fahlenbrach and Stulz (2011) document a negative relationship between bank performance during the crisis and the stock-option holdings of bank CEOs just before the crisis, arguing that CEOs provided with better incentives to maximize shareholders' welfare may have taken on more risk. They conjecture that excessive risk-taking might have been profitable for bank shareholders from an ex-ante perspective but turned into unexpected losses ex-post. Laevin and Levin (2009) and Pathan (2009) find explicit evidence that higher bank risk-taking is positively associated with stronger shareholders' power.

[2] For example, anecdotal evidence suggests that the top managers of the Bank of the Commonwealth failed in 2011 intentionally fostered the provision of bad loans in return for favors.

the regulator seeks to prevent imprudent risk management via incentive-based capital requirements.

I begin by addressing the incentive-based design of capital requirements in the hypothetical setting in which the manager acts in the interests of bank shareholders. Minimum capital requirements in the model take the form of the *regulatory threshold* such that the bank will be subject to mandatory liquidation as soon as the value of its assets falls below this critical level. In this regard, the model shares the same feature as the existing studies dealing with incentive-based capital requirements aimed at preventing banks from taking on higher *volatility risk* (see e.g. Bhattachariya, Planck, Strobl and Zechner (2002), Décamps, Rochet and Roger (2004), Koziol and Lawrenz (2012)). A key departure from these studies is that, in the present setting, bank shareholders are given the possibility to comply with minimum capital requirements by issuing new equity to finance asset expansions. In fact, a sufficiently high regulatory threshold triggering immediate liquidation can prevent a bank from taking on higher *volatility risk* that induces small and frequent shocks on the bank asset value. Yet, even when set at an extremely high level, it turns out to be unable to eliminate incentives for taking on *tail risk* that induces infrequent but large negative shocks. The reason is that, if shareholders have no possibility of avoiding mandatory liquidation when the bank asset value is brought down to the regulatory threshold, the value of bank equity in the neighborhood of the regulatory threshold becomes tiny, given that continuation perspectives are weak. As a result, bank shareholders have almost nothing to lose in the case if the minimum capital requirements are breached following a large loss, which induce them to "gamble for resurrection" by implementing imprudent risk management. In other words, if bank shareholders have no means for complying with minimum capital requirements, the desire to avoid imminent liquidation caused by the adverse realization of volatility risk would induce taking on tail risk.

In contrast, when bank shareholders have the possibility to comply with minimum capital requirements via costly recapitalizations leading to asset expansion, it becomes possible to prevent the bank from engaging in tail risk. The regulatory threshold in this case should be designed so as to ensure that bank shareholders would prefer to undertake costly recapitalization rather than to accept mandatory liquidation, which would rule out the possibility to default because of adverse realizations of volatility risk. This feature generates two incentive effects complementing each other. First, the value of equity in the neighborhood of the regulatory threshold will remain relatively high, thereby, making bank shareholders sensitive to the threat of mandatory liquidation if a large loss leads to the violation of minimum capital requirements. The second incentive effect enters into play when the bank asset value is relatively strong and the threat of breaching minimum capital requirements following a large loss is irrelevant. Here, shareholders will internalize the fact that negative shocks to bank asset value under tail risk will raise the probability of reaching minimum capital requirements, so that engaging in tail risk will entail higher expected costs of compliance with capital regulation. Under the appropriate calibration of the regulatory threshold, these two effects will eliminate incentives for taking on tail risk. In the perspective of policy debates, this set of results suggests that it is not only the level of minimum capital requirements that matters for discouraging banks from manufacturing tail risk, but also the possibility to make bank shareholders bear the private costs of compliance with capital regulation.

After describing the design of incentive-based capital regulation for the manager-owned bank, I reexamine it in the context of the internal agency problem. Providing the manager with the incentives to stick to prudent risk management is costly. If the regulatory threshold is not high enough, shareholders may be better off tolerating imprudent risk management in their bank. Thus, to be able to prevent imprudent risk management in the context of the internal agency problem, the regulatory threshold should be designed while taking into account the shareholders' costs of the optimal incentive compensation contract that would prevent the manager from engaging in tail risk. This feature differentiates the proposed capital regulation design from existing capital regulation approaches, which do not attach great importance to the internal agency problem between bank shareholders and bank managers.

The optimal incentive compensation contract in this paper is derived under assumption that managerial compensation is contingent on the bank asset value. This assumption establishes the link between the size of managerial pay and the assets' size suggested by Gabaix and Landier (2008) and helps integrate information on incentive compensation into the capital regulation design while keeping the model tractable. Incentives to the manager are provided by the joint use of two incentive tools: the sensitivity of compensation to the changes of the bank asset value and the threat of contract termination conditional on the arrival of a large loss. Under the optimal incentive contract, the manager will never engage in tail risk and will remain in his position forever. The latter feature is related to the fact that, unlike the existing dynamic models on optimal contracting such as Sannikov (2008), He (2009) and DeMarzo, Livdan and Tchistyi (2013), the contract continuation value remains strictly positive, regardless of the state of the bank asset value (this is because, under the properly designed capital regulation, the bank never ceases operating). As a result, in the case of contract termination, the manager would have to be offered a positive terminal pay-off equal to the expected value of the further contract payoffs he could obtain from continuation. However, this would inefficiently increase the total costs of incentive compensation to bank shareholders, so that it would be optimal to keep the same manager provided no loss occurs. In the context of this paper, this result suggests that firing the manager would be inefficient, if bank asset value is brought down by the adverse realization of volatility risk rather than by a large loss. At the same time, the ex-ante threat of contract termination in the case of large losses is essential for the optimal contract design.

The nature of the moral hazard problem studied in this paper situates it close to the work of Biais, Mariotti, Rochet and Villeneuve (2010). In their model, the agent's effort affects a firm's exposure to tail risk, given that lower effort enables the manager to collect private benefits proportional to the firm's size. However, they consider tail risk to be the sole type of risk the firm faces, whereas in the present paper, bank asset value is also affected by volatility risk. Both types of risks are present in the model of DeMarzo, Livdan and Tchistyi (2013), who design an optimal contract in a two-dimensional setting, where the manager privately chooses between two risk regimes, while having the possibility to divert part of the firm's cash flow. The optimal incentive contract in their setting allows the manager to take on tail risk when his continuation value becomes relatively low. In the present paper, the manager controls asset growth, rather than bank assets' cash flows. Moreover, the optimal incentive contract is designed in such a way as to discourage the manager from taking on tail risk.

Makarov and Plantin (2012) also design the optimal incentive contract that prevents the fund manager from taking on tail risk. However, in their model, the manager's incentives to take on tail risk are driven by different considerations than in the present paper. Namely, in Makarov and Plantin (2012), managerial compensation explicitly depends on the investors' perception of the manager's ability to generate excess returns, so that taking on tail risk allows the manager to manipulate investors' beliefs about his skills in order to receive higher awards. The optimal compensation contract in such a framework is characterized by a sequence of random payments delivered with the intensity depending on realized performance. In the present paper, the optimal incentive contract is contingent on bank asset value and relies essentially on the appropriate choice of the sensitivity of managerial compensation to the changes of bank asset value.

By incorporating information on the incentive managerial compensation into the design of capital requirements, the present paper connects the literature on the optimal contracting in the dynamic framework with the vast capital regulation literature. However, I am not the first to point out the need to account for the internal agency problem in the capital regulation design. Bris and Cantale (2004) placed emphasis on this issue when examining the impact of capital requirements on the effort choice of a self-interested risk-averse bank manager in a discrete-time framework. They find that capital regulation, which does not take into account the internal agency problem between bank shareholders and the bank manager, leads to a socially-suboptimal choice of the *lower* level of risk. In contrast, the present study shows that, in the context of tail risk and with risk-neutral agents, the bank may operate at the higher level of risk if capital regulation fails to account for the internal agency problem. In addition, I explicitly show how to adapt the optimal design of capital regulation to take account of the internal agency problem in order to prevent socially undesirable risk.

The remainder of the paper is organized as follows. Section 2 presents the model. Section 3 studies the bank's incentives to take on tail risk. Section 4 presents a benchmark case in which the optimal incentive capital requirements are designed in the setting free of the internal agency problem. Section 5 reexamines the optimal design of capital requirements, allowing for the internal agency problem. In Section 6, several related regulatory policy issues are discussed. Section 7 concludes. All proofs and technical details are gathered in the Appendices.

# 2 The model

Consider a risk-neutral environment where all agents discount future cash flows at a constant rate $r$. There is a bank protected by limited liability. The bank is financed by a constant volume of insured deposits, $D$, and incurs continuous interest payments $rD$ to depositors. The bank's asset portfolio consists of non-tradable illiquid loans with an aggregate value $x_t$, which is assumed to be publicly observable.[3] Bank assets continuously generate a cash-flow $\delta x_t dt$, so that the net payoff to shareholders after making interest payments to depositors amounts to $(\delta x_t - rD)dt$.[4]

The bank is run by a manager who has a reversible discretionary choice between two risk management strategies: prudent and imprudent. *Imprudent* risk management strategy generates higher expected asset growth rate $\mu$. However, it involves infrequent but large losses (tail risk). Large losses caused by tail risk materializing follow a Poisson process $\{N_t\}_{t\geq 0}$ with intensity $\lambda$. A large loss destroys a fraction $(1-\alpha)x_t$ of bank assets, where $\alpha \in (0,1)$ is a constant coefficient which reflects the proportion of assets remaining after the large loss is realized. Under *prudent* risk management strategy, the bank is fully protected from tail risk, but the bank asset value is growing at a lower expected rate, $(\mu - \Delta\mu)$, where $\Delta\mu > 0$. For the rest of the paper, it is assumed that $\Delta\mu \leq \lambda(1-\alpha)$ and $\delta + (\mu - \Delta\mu) < r$. The former condition implies that imprudent risk management is suboptimal from a social point of view. Under the latter condition,

[3] Following Rochet (2004) and Pennacchi (2010), I assume that the value of bank assets can be inferred from the market value of shareholders' equity.

[4] Since the model does not address the optimal choice of the bank's financing structure, the tax rate is set to zero.

a one-dollar investment in bank assets would generally be less rewarding than a one-dollar investment in riskless security, which makes expanding bank assets via new equity issuance unattractive to bank shareholders.

Let $s_t \in \{0, 1\}$ be an indicator of risk-management strategy implemented at time $t$, where $s_t = 0$ refers to the choice of imprudent risk management. Then, bank asset value evolves according to

$$\frac{dx_t}{x_t} = (\mu - s_t \Delta\mu)dt + \sigma dZ_t - (1 - s_t)(1 - \alpha)dN_t, \tag{1}$$

where $\sigma$ is the asset return volatility and $\{Z_t\}_{t \geq 0}$ is a standard Brownian motion whose increments reflect small and frequent shocks to the bank asset value.

Expression (1) highlights the trade-off between faster asset growth and risk management quality that many banks faced in the years prior to the global financial crisis. Indeed, practices like aggressive subprime lending, extensive investment in structured products, creative accounting and involvement in any kind of illegal activities may allow the bank to benefit from higher profits in the short-run but may also lead to large losses in the long run.[5]

While bank shareholders may be interested in imprudent risk management because of the faster asset growth it may bring in the short run, the main interest for the manager to adopt imprudent risk management relates to the possibility of collecting private benefits. As in Biais, Mariotti, Rochet and Villeneuve (2010), private benefits are assumed to be proportional to the asset size and amount to $bx_t dt$ per unit of time. For the reminder of the paper, this potential divergence of bank shareholders' and manager's incentives with respect to choice of risk-management strategy is labeled as the *internal agency problem*.

Since large losses incurred by a single bank may inflict negative externalities on the rest of the economy, especially when they lead to the bank's failure, I assume that the objective of the bank regulator is to prevent imprudent risk management by using incentive-based capital requirements. In practice, minimum capital requirements are implemented in the form of capital ratios, which leaves banks three possible options to comply with capital regulation (see e.g. Admati, DeMarzo, Hellwig and Pfleiderer (2011)). These options include (i) deleveraging through asset liquidation; (ii) issuing equity to replace debt, while keeping the volume of assets unchanged; and (iii) raising new equity to expand assets. Yet, the first two options might involve considerable social costs. Deleveraging

[5]That was the very scenario that led the Bank of the Commonwealth to its demise in 2011. Among the more recent examples of materialized tail risk engendered by the banks themselves, one may consider the huge fines imposed in 2014 by the U.S. Department of Justice on Credit Suisse and BNP Paribas for implications in tax frauds and money laundering, as well as on the Bank of America for knowingly selling bad mortgage loans to investors.

through asset liquidation reduces lending capacity of banks, which may result in a credit crunch and thus may harm economic growth. Moreover, massive deleveraging by banks may draw asset prices down, which would create negative externalities for the rest of the financial sector. In this light, changing liability structure without changing the size of the asset portfolio may be less harmful than pure deleveraging. However, this would reduce the supply of deposits to the economy and, thereby, cannot be considered as socially costless. In contrast, the third option leading to asset expansion would preserve both lending capacity and the supply of deposits.[6]

To leave the bank only the third option to comply with capital regulation, I assume that minimum capital requirements are implemented in the form of a regulatory threshold $x_R$, such that the bank will be liquidated if the bank asset value falls below this critical threshold. In the case of bank liquidation, the regulator will expropriate the incumbent shareholders, restructure the bank and sell it to new owners. Thus, the incumbent shareholders are given the following choice: to maintain bank asset value above $x_R$, by raising new equity and expanding assets or to be deprived of equity when not complying with capital requirements.[7]

Asset expansion involves both proportional and lump-sum costs denoted by $\xi_1$ and $\xi_0$ respectively. These costs comprise registration costs of new equity issues and, in particular, asset adjustment costs. Specifically, when the fresh capital raised from bank shareholders is used to provide loans to the creditors who previously had no lending relationships with the bank, asset adjustment costs can be thought of as the costs of collecting information about these new creditors, as well as transaction and negotiation costs. Let $(\tau_n)_{n\geq 1}$ denote the sequence of asset expansion dates and let $(z_{\tau_n})_{n\geq 1}$ denote the sequence of expansion factors, such that $z_n x_{\tau_n} > 0$ is the amount of fresh equity capital used to expand bank assets at time $\tau_n$. Then, at time $t$, the cumulative costs of asset expansions will be given as follows:

$$I_t = \sum_{n\geq 1} \left((1+\xi_1) z_{\tau_n} x_{\tau_n} + \xi_0\right) \mathbb{1}_{\tau_n \leq t}. \tag{2}$$

Notice that, in order to ensure the continuity of debt service when the asset cash-flow does not suffice to make interest payments to depositors, i.e., $\delta x < rD$, shareholders also have to issue new equity. However, as in the classical structural model of Leland

[6]One may argue that inducing bank shareholders to raise new equity in order to expand assets would increase the bank's size and, thereby, would exacerbate the "too big to fail" problem. Yet, the fact that a bank has attained minimum capital requirements suggests that bank assets have already substantially shrunk, so that asset expansion would just restore the "normal" size of the bank.

[7]In line with the standard assumption of the structural Leland-type models, shareholders are assumed to have "deep pockets".

(1994), equity issuance is assumed to be costless in that case.[8] This assumption is made to put an emphasis on the fact that, when new equity is issued to service debt obligations, the structure of bank assets remains intact, so that shareholders do not incur any asset adjustment costs.

The possibility to comply with capital requirements via costly recapitalization leading to asset expansion marks a key difference between the current framework and the existing structural models sharing the similar incentive-based approach to capital regulation design (see e.g. Décamps, Rochet and Roger (2004), Rochet (2004), Koziol and Lawrenz (2012)). The next section offers an analytical argument to account for this mechanism when designing the incentive-based capital regulation in the context of tail risk.

# 3 Tail risk and capital regulation

To show the need for capital regulation in the above set-up, it is useful first to consider the optimal risk-management strategy of the bank in the absence of capital regulation. Throughout this section, I will abstract from the internal agency problem, analyzing risk management decisions of the owner-managed bank.

In the absence of any regulation, bank shareholders maximize equity value, $E(x)$, by deciding which risk management strategy to implement conditional on the state of the bank asset value. By the standard dynamic programming arguments, equity value satisfies the Bellman equation:

$$rE(x) = \max_{s\in\{0,1\}} \left\{\frac{1}{2}\sigma^2x^2E''(x)+(\mu-s\Delta\mu)xE'(x)-(1-s)\lambda(E(x)-E(\alpha x))+\delta x-rD\right\}. \tag{3}$$

The term on the left-hand side of equation (3) refers to the expected return from holding bank equity. The first two terms on the right-hand side reflect the expected changes in the value of equity caused by the changes in the value of the underlying assets. The third term on the right-hand side captures the possibility of experiencing a sudden drop in the value of equity if imprudent risk management is implemented, and $\delta x - rD$ refers to the net shareholders' profit.

Expression (3) highlights that the choice of the optimal risk management strategy is governed by a trade-off between the instantaneous gain from imprudent risk management and the expected loss of equity value caused by tail risk realization. Since the right-hand side of (3) is linear in $s$, implementing prudent risk management is optimal as long as

[8] Relaxing this assumption would bring unnecessary complications in the analysis, without changing the main findings. I verify the robustness of incentive-based capital requirements in the presence of such a type of equity issuance costs in Appendix D.

the expected negative jump of equity value caused by tail risk realization exceeds the marginal increase in equity value generated by imprudent risk management, i.e.,

$$\lambda(E(x) - E(\alpha x)) \geq \Delta\mu x E'(x). \tag{4}$$

Condition (4) will be further referred to as the incentive compatibility condition of bank shareholders. Assume that this condition *always holds* in the absence of any regulatory control so that the bank would forever stick to prudent risk management. Under condition $\delta + (\mu - \Delta\mu) < r$, an increase in the value of equity generated by asset expansion would be always less than the value of capital injected by shareholders, even if the costs related to asset expansions were zero.[9] As a result, bank shareholders would never raise new equity in order to finance asset expansions and would close the bank, as soon as the bank asset value attains a certain liquidation threshold $x_L^*$ chosen so as to maximize the value of equity. Plugging $s = 1$ into the ODE (3) and solving the latter under the boundary condition $E(x_L^*) = 0$ and no-bubble condition $\lim_{x\to\infty} E(x) \to \delta x - rD$ would yield the following expression for equity value:

$$E(x) = \nu\delta x - D + (D - \nu\delta x_L^*)\left(\frac{x}{x_L^*}\right)^{\beta_2}, \tag{5}$$

where $\beta_2 < 0$ is a negative root of characteristic equation $1/2\sigma^2\beta(\beta - 1) + \mu\beta = r$ associated with the ODE (3), $\nu = (r - \mu + \Delta\mu)^{-1}$ and the optimal default threshold $x_L^*$ (such that $\partial E(x)/\partial x_L^* = 0$) is given by

$$x_L^* = \frac{\beta_2}{\beta_2 - 1}\frac{D}{\nu\delta}. \tag{6}$$

Yet, given the value of equity defined in (5), verification of the incentive compatibility condition of bank shareholders shows that the latter is violated in the neighborhood of the optimal liquidation threshold $x_L^*$. Thus, the following result is obtained by contradiction.

**Proposition 1** *In the absence of any regulatory control, sticking forever to prudent risk management is never optimal for bank shareholders.*

Indeed, distressed banks may have incentives to "gamble for resurrection", optimally engaging in tail risk in order to increase asset growth and, thereby, to delay liquidation. In such a context, capital regulation is needed in order to prevent the bank from engaging in tail risk.

[9] Formally, this is captured by condition $E'(x) < 1$, which can be easily verified by using the expression of equity value provided in (5). Indeed, one can observe that $\lim_{x\to x_L^*} E'(x) \to 0$, $E''(x) > 0$ and $\lim_{x\to\infty} E'(x) \to \nu\delta < 1$.

Before the recent financial crisis revealed the acute problem of "manufactured" tail risk in the banking sector, one of the central themes of the literature on bank capital regulation has been the asset substitution problem. This problem refers to the bank owners' incentives to pick assets with higher volatility risk, without regard for the negative externalities related to such a choice. A number of papers dealing with this issue in the context of Leland-type structural models[10] showed that it is possible to prevent a bank from choosing assets with higher volatility risk, $\sigma$, through an incentive-based regulatory threshold, such that shareholders have no choice but to face mandatory liquidation as soon as the bank asset value hits this regulatory threshold. The natural question is whether a simple threat of mandatory liquidation is sufficient to prevent the bank from engaging in tail risk.

Assume for a moment that expanding bank assets via new equity injections is prohibitively costly and consider any arbitrary regulatory liquidation threshold $x_L \geq x_L^*$. Once again, verification of the incentive compatibility condition (4) shows that the latter doesn't hold when bank asset value approaches $x_L$. This is because, in the neighborhood of the liquidation threshold, the value of equity becomes too weak, so that the expected benefits from taking on tail risk would outweigh the expected loss of equity value caused by the realization of a large loss. Namely, taking on tail risk may help the distressed bank to increase asset growth and, thereby, to avoid imminent liquidation caused by adverse realizations of volatility risk. The following proposition summarizes this result.

**Proposition 2** *If shareholders have no choice but to face mandatory liquidation when bank asset value hits the regulatory threshold following adverse realizations of volatility risk, capital regulation would be unable to discourage the bank from taking on tail risk.*

Proposition 2 stipulates that a mere increase in capital requirements will be insufficient to deal with "manufactured" tail risk in the banking sector if bank shareholders have no means of avoiding mandatory liquidation upon reaching the regulatory threshold. As will be shown below, the incentives to take on tail risk can be eliminated if (i) bank shareholders have the possibility to ensure compliance with capital requirements by issuing new equity and expanding bank assets, *and* (ii) minimum capital requirements are designed in such a way so as to induce them to use this possibility rather than to accept mandatory liquidation. The intuition is that, when bank shareholders have incentives to undertake costly asset expansions in order to comply with capital requirements, the possibility to default because of adverse realizations of volatility risk is ruled out. As a result, the value of bank equity in the neighborhood of the regulatory threshold would

[10] See e.g. Bhattachariya, Planck, Strobl and Zechner (2002), Décamps, Rochet and Roger (2004), Koziol and Lawrenz (2012).

remain relatively high, and bank shareholders would have "something to lose" in the case that a large loss brings bank asset value below the regulatory threshold. In addition, even when bank asset value is relatively strong (so that the threat of mandatory liquidation in the case of a large loss is irrelevant), shareholders will internalize the fact that negative shocks to bank asset value will increase the frequency of hitting minimum capital requirements, thereby raising the total expected costs of asset expansions. Under the appropriate calibration of the regulatory threshold, these two effects can discourage the bank from engaging in tail risk. The next two sections take a detailed look at the design of incentive-based regulatory threshold, allowing for the possibility of a costly compliance with minimum capital requirements.

# 4 Capital regulation for the owner-managed bank

In order to track the impact of the internal agency problem on capital regulation, I start by looking into the design of incentive-based capital requirements in a setting, where the interests of the bank manager are perfectly aligned with the interests of bank shareholders. In what follows, I will refer to this setting as the benchmark case.

Consider the regulatory problem. The regulator is looking for the optimal regulatory threshold $x_R$ which will induce the bank to stick to prudent risk management for all $x \geq x_R$ while maximizing bank social value, $V(x)$. Bank social value is equal to the sum of bank equity value and the market value of deposits net of any social costs $\phi(x)$ related to bank liquidation or any regulatory measures, i.e., $V(x) = E(x) + D - \phi(x)$. Due to deposit insurance, the market value of deposits is constant over time. At the same time, under reasonable costs of asset expansions (for the rest of the analysis, I stick to this scenario), there will be no bank liquidation ex-post, so that $\phi(x) \equiv 0$. As a result, under the condition that the bank will stick to prudent risk management, the maximization of bank social value will be equivalent to the maximization of bank equity value.[11]

Determining the optimal incentive-based regulatory threshold requires knowledge of the optimal decisions that will be made by bank shareholders in response to capital regulation. Indeed, faced with minimum capital requirements implemented in the form of the regulatory threshold, bank shareholders will decide: (i) whether to comply with capital requirements via costly asset expansions or just accept mandatory liquidation when breaching the regulatory threshold? (ii) if the first alternative is better, how much equity must be issued to finance asset expansion? (iii) which risk-management technology

[11] It is worthwhile mentioning that the regulatory problem wouldn't change if bank liabilities were to comprise uninsured debt. In fact, under incentive-based capital requirements, the bank will never default and uninsured debt will be risk free.

should be implemented depending on the state of the bank asset value?

As was discussed in the previous section, in the absence of capital regulation, bank shareholders can optimally choose when to liquidate the bank. Hence, under condition $\delta + (\mu - \Delta\mu) < r$, undertaking costly asset expansions would not make any sense. However, under minimum capital requirements, the bank is faced with a threat of premature liquidation, so that the asset-expansion option might be used to avoid it. Whether compliance with capital requirements via asset expansions dominates liquidation depends on the costs of asset expansion and the level of the regulatory threshold. As will become apparent from the analysis below, asset expansion is valuable for shareholders when the proportional costs of asset expansion are relatively low and the regulatory threshold is relatively high.

Given condition $\delta+(\mu-\Delta\mu) < r$ and the fixed costs of asset expansions, it is reasonable to conjecture that bank shareholders will not undertake asset expansions as long as the bank asset value exceeds the regulatory threshold (this conjecture will be verified ex-post). Thus, unless mandatory liquidation dominates costly asset expansion, the optimal strategy of bank shareholders will be to finance asset expansions by raising new equity $zx_R$ whenever the bank asset value hits the regulatory threshold $x_R$. Furthermore, the asset expansion factor, $z$, will be selected so as to maximize the value of the shareholders' claim.

Finally, bank shareholders would forever stick to prudent risk management under condition:

$$\lambda(E(x) - \mathbb{1}_{x \geq x_R/\alpha} E(\alpha x)) \geq \Delta\mu x E'(x), \quad x \geq x_R, \tag{7}$$

which is obtained by the immediate adaptation of the incentive compatibility condition (4), resulting from the maximization problem of bank shareholders. Here, the indicator function $\mathbb{1}_{x \geq x_R/\alpha}$ reflects the fact that a large loss incurred in the region $[x_R, x_R/\alpha)$ would trigger bank liquidation.

Taking into account the above considerations, the regulatory problem can be stated as follows:

$$\max_{x_R > 0, z > 0} \quad E(x) \geq 0 \qquad \text{subject to (7).}$$

In the above problem, equity value represents the expected discounted value of future operating profits net of the total costs of asset expansions:

$$E(x_t) = \mathbb{E}\left[\int_t^{+\infty} e^{-r(\tau-t)}(\delta x_\tau - rD)d\tau - \int_t^{+\infty} e^{-r(\tau-t)} dI_\tau\right], \tag{8}$$

where $x_t$ follows (1) with $s_t = 1$ and $I_\tau$ is given by (2) with $x_{\tau_n} = x_R$, $z_{\tau_n} = z$ for any given $\tau_n \leq t$. As shown in Appendix A.1, one can obtain a simple closed-form expression for the value of equity:

$$E(x) = \nu\delta x - D - \Omega(x_R, z)x^{\beta_2}, \tag{9}$$

where

$$\Omega(x_R, z) = \left[\frac{\xi_0 + (1 + \xi_1 - \nu\delta)zx_R}{1 - (1+z)^{\beta_2}}\right] {x_R}^{-\beta_2} > 0.$$

To gain some intuition on the solution to the regulatory problem, observe that maximizing equity value is actually equivalent to minimizing the expected costs of compliance with capital regulation reflected by $\Omega(x_R, z)$. Given any arbitrary expansion factor $z > 0$, consider the choice of the optimal incentive-compatible regulatory threshold. Since $\Omega(x_R, z)$ is increasing with $x_R$, the maximum equity value will be attained under the minimum feasible incentive-based regulatory threshold that makes the incentive constraint (7) binding at $x = x_R$. Plugging equity value (9) into the binding incentive constraint (7) and solving the obtained equation with respect to $x_R$ yields a simple analytical characterization of the optimal regulatory threshold which would deter the owner-managed bank from taking on tail risk:[12]

$$x_R^B(z) = \frac{h_0(z)}{h_1(z)}, \tag{10}$$

where the expressions for $h_0(z)$ and $h_1(z)$ are provided in Appendix B.

Given the regulatory threshold $x_R^B(z)$, the expected loss of equity value under tail risk exposure would always exceed the instantaneous gain from imprudent risk management, which will induce the bank to stick to prudent risk management. Moreover, it can be verified that, irrespective of the chosen asset expansion factor $z$, equity value remains strictly positive at $x_R^B(z)$, so that, at this point, shareholders will prefer to undertake costly asset expansion rather than face mandatory liquidation. At the same time, faced with the regulatory threshold $x_R^B(z)$, shareholders will have no interest in undertaking voluntary asset expansions at any $x > x_R^B(z)$, since the costs of asset expansions would always exceed the expected growth of equity value that would result from capital injections.

It is shown in the Appendix that $x_R^B(z) > 0$ exists if and only if the proportional costs of asset expansion do not exceed a certain critical level $\bar{\xi}_1(z)$.[13] Let

$$z^* = \arg\min \quad \Omega(x_R^B(z), z)$$

[12] The model framework can also accommodate the presence of the proportional equity issuance costs when new equity is issued to ensure interest payments to depositors for $x < rD/\delta$ (see Appendix D). In this case, it is still possible to prevent tail risk by using of the incentive-based regulatory threshold which makes the incentive constraint of bank shareholders binding. The robustness of this result hinges on the concavity of the equity value function.

[13] At the same time, the existence of the solution to the regulatory problem does not depend on the magnitude of the fixed costs of asset expansion, $\xi_0$. From the complete expression of $x_R^B(z)$ provided in the Appendix B, one can easily see that, for any level of $\xi_0$, there exists a corresponding minimum incentive-based regulatory threshold.

denote the asset expansion factor maximizing the bank equity value constructed under the incentive-based regulatory threshold $x_R^B(z)$. Then, the optimal design of incentive-based capital regulation in the absence of the internal agency problem can be characterized as follows:

**Proposition 3** *When the proportional costs of asset expansions are relatively low, i.e.,* $\xi_1 < \overline{\xi}_1(z^*)$*, the regulator can prevent the bank from engaging in tail risk via the optimal regulatory threshold*

$$x_R^B(z^*) = \frac{h_0(z^*)}{h_1(z^*)},$$

*such that the bank will be subject to liquidation if the value of its assets falls below* $x_R^B(z^*)$*.*

The incentive power of the proposed capital regulation design is anchored in the two effects related to the fact that $x_R^B(z^*)$ is constructed in such a way that shareholders will find it optimal to undertake costly asset expansions upon reaching the regulatory threshold. First, the possibility of complying with minimum capital requirements via costly asset expansions prevents the value of equity from being too weak when the value of underlying assets is relatively low. This makes bank shareholders sensitive to the threat of mandatory liquidation conditioned on the arrival of a large loss in the region $[x_R^B(z^*), x_R^B(z^*)/\alpha)$.[14] Second, when bank asset value is relatively strong and the threat of mandatory liquidation in the case of a large loss is irrelevant, i.e, $x \geq x_R^B(z^*)/\alpha$, another incentive effect is activated. Here, shareholders will internalize the fact that, under large losses caused by imprudent risk management, the bank asset value would deteriorate more quickly, which would increase the likelihood of reaching the regulatory threshold and, thereby, would amplify the expected costs of compliance with minimum capital requirements.[15] Thus, it turns out that making bank shareholders bear the costs of compliance with capital regulation is essential for inducing them to stay away from imprudent risk management. As suggested by Admati, Conti-Brown and Pfleiderer (2012), in practice, this might be achieved by creating equity-funded Liability Holding Companies, which would support the increased liability of systemically important banks' equity.

To get an idea about the order of magnitude of the optimal incentive-based capital requirements, I resort to numerical examples. The values of the model parameters are set

[14]In contrast, if the proportional costs of asset expansions are too high or the regulatory threshold is low, bank shareholders would have no incentives to undertake costly asset expansions. As a result, bank equity value would be weak in the neighborhood of the regulatory threshold, so that the benefits of imprudent risk management would outweigh the expected loss of equity value. As shown by Proposition 2, it would be impossible to eliminate incentives for taking on tail risk in this case.

[15]The long-run impact of capital adjustment costs cannot be captured by a static model, which may explain the divergence of the obtained results with that of Perotti, Ratnovski and Vlahu (2011) who find that tighter capital regulation may induce the bank to take on tail risk even in the presence of capital adjustment costs.

as follows: the volume of deposits is normalized to one, the risk-free interest rate $r = 4\%$, the asset return volatility $\sigma = 20\%$, the expected asset growth rate under imprudent risk management $\mu = 2.5\%$, the expected asset growth rate under prudent risk management $(\mu - \Delta\mu) = 2\%$, the cash-flow rate $\delta = 1.9\%$, the intensity of large losses $\lambda = 0.15$, the residual fraction of assets after a large loss $\alpha = 0.9$, proportional costs of asset expansion $\xi_1 \in [1\%, 10\%]$ and lump-sum costs of asset expansion $\xi_0 \in [0.1 \times 10^{-4}, 0.1 \times 10^{-3}]$. This parameter set is calibrated for the exposure to 10 percent losses occurring on average once every 6-7 years. Parameters $\mu$, $\Delta\mu$ and $\delta$ are set to comply with assumptions $\Delta\mu \leq \lambda(1 - \alpha)$ and $\delta + (\mu - \Delta\mu) < r$. The proportional costs of asset expansion vary in the range reflecting the existing empirical evidence on the average marginal costs of equity issuance.[16] The fixed costs of asset expansions are controlled to not exceed 10% of the capital injection.

In this numerical example, the optimal incentive-based regulatory threshold $x_R^B(z^*)$ varies in the range of $(1.15, 1.25)$, and the optimal asset expansion factor $z^*$ takes values between $(0.01, 0.03)$. For example, for $\xi_0 = 0.1 \times 10^{-3}$ and $\xi_1 = 0.05$, one obtain $x_R^B(z^*) \approx 1.1912$ and $z^* \approx 0.0263$, which would correspond to the minimum capital ratio of 16% and 2.6% asset growth resulted from asset expansion.[17]

Comparative statics results reported in Appendix C show that the optimal regulatory threshold $x_R^B(z^*)$ is increasing on both fixed and proportional costs of asset expansions. Indeed, under the significant costs related to asset expansions, continuation should be valuable enough to induce shareholders to prefer a costly asset expansion over bank liquidation. The choice of the optimal expansion factor $z^*$ is governed by the interplay between two opposite effects generated by the fixed and proportional costs of asset expansions: $z^*$, as well as the optimal scale of asset expansion, $z^* x_R^B(z^*)$, is increasing on $\xi_0$ and decreasing on $\xi_1$. Indeed, higher fixed costs induce shareholders to undertake larger asset expansions in order to build stronger capital buffer and thus to delay the next event of costly asset expansion, whereas higher proportional costs reduce the shareholders' capacity of asset expansions. Lastly, it can be mentioned that the optimal regulatory rule $x_R^B(z^*)$ is increasing with asset return volatility $\sigma$, since higher $\sigma$ exacerbates incentives to take on tail risk. At the same time, $x_R^B(z^*)$ decreases with the intensity of large losses $\lambda$. Indeed, for any given $\Delta\mu$, higher intensity of large losses would reduce shareholders' incentives for engaging in tail risk, thereby allowing for less stringent capital requirements.

Before turning to the design of the capital regulation under the internal agency prob-

[16] For example, the average marginal equity issuance costs are estimated at 2.8% in Gomes (2001), 5.1% in Altinkiliç and Hansen (2000), 10.7% for small firms and 5% for large firms in Hennessy and Whited (2007).

[17] In the current framework, the minimum capital ratio coincides with the leverage ratio and can be computed as the ratio of the book value of equity to total assets: $100\% \times (x_R^B(z^*) - D)/x_R^B(z^*)$.

lem, it would be useful to discuss one caveat that refers to the rigid payout policy inherited from the seminal structural model of Leland (1994). Yet, intuition suggests that, instead of sticking to a rigid payout policy, bank shareholders might be better off reinvesting a fraction of the asset cash-flow in order to increase the expected asset growth rate and thus to reduce the probability of hitting the regulatory threshold triggering costly asset expansion. Indeed, numerous numerical experiments show that $E'(x) > 1$ when $x \to x_R^B(z^*)$. Thus, because of the aversion to costly asset expansions, shareholders may be willing to reinvest a fraction of the asset cash-flow when approaching the regulatory threshold. This is actually the concavity of the equity value function coupled with the presence of the regulatory constraint that suggests the relevance of the endogenous payout policy.[18]

To sharpen the analysis, in the Appendix E, I build an extended version of the benchmark-case model that accommodates the above considerations. To handle the endogenous payout decisions while preserving the main properties of the process driving the bank asset value, I follow Diamond and He (2014), by presuming that bank shareholders have an option to reinvest a part of the asset cash-flow at a constant rate, without incurring any fixed asset adjustment costs. Reinvestment, however, may involve some proportional deadweight costs, which would reduce the effective reinvestment rate. The numerical analysis conducted for this version of the model delivers a number of interesting predictions. First, it confirms that shareholders would find it optimal to use the reinvestment option only when the bank is in a deep distress. Therefore, it is the very aversion to the costs of compliance with minimum capital requirements that can induce shareholders to hedge against the consequences of the adverse realization of volatility risk by scarifying dividend payments (or raising additional equity to ensure the continuity of debt service) in order to increase the expected asset growth rate. Second, the higher deadweight costs of reinvestment would raise the need for tighter capital regulation.[19] In fact, instead of undertaking reinvestment that involves deadweight costs, bank shareholders may obtain the desired increase in the expected asset growth rate by engaging in tail risk. Higher deadweight costs of reinvestment would make the second alternative more attractive to shareholders, so that a higher regulatory threshold should be imposed to offset these perverse incentives. Finally, I use this extended version of the model in order to explore the implications of the additional regulatory measure that would re-

[18] In this respect, the present model substantially differs from the classical structural model of Leland (1994), in which shareholders optimally choose when to liquidate the firm. Because of the optimal choice of the liquidation threshold, the first derivative of the shareholders' claim in the Leland's model never exceeds one, thereby, making reinvestment suboptimal.

[19] For relatively high levels of the deadweight costs, reinvestment would be suboptimal, so that the design of the optimal incentive-based regulatory threshold would be exactly the same as described in Proposition 3.

strict payouts to shareholders below a certain critical level of the bank assets value.[20] Interestingly, restricting payouts to shareholders turns out to be counterproductive: the numerical analysis reveals that constraining payouts at a higher level of the bank assets value would require raising the optimal incentive-based regulatory threshold. The reason is that tighter payout restrictions would reduce the bank's franchise value, thereby, weakening the shareholders' incentives to inject capital into the bank in order to ensure compliance with minimum capital requirements. This would in turn exacerbate the shareholders' incentives for taking on tail risk and thus would raise the need for tighter capital requirements. Put differently, this result suggests that regulatory interventions into the bank's payout policy, when the bank is subject to moral hazard regarding the choice of risk management quality, may undermine the stability of the banking sector, unless they are not complemented by stricter capital regulation.

# 5 Capital regulation under the internal agency problem

Consider now the set-up which allows for the internal agency problem. Here, shareholders have to make two strategic decisions: (i) whether to promote prudent risk management in their bank and (ii) if so, how to create the appropriate incentives for the manager at minimum cost. I start by answering the second question, defining the optimal incentive contract with the manager. Then I use information on the optimal incentive contract to design the optimal incentive regulatory threshold, which will induce shareholders to put this contract in place.

## 5.1 The optimal incentive contract

Assume there exists some incentive regulatory threshold $x_R$ under which shareholders find it optimal to promote prudent risk management in their bank for all $x \geq x_R$. Then, what will be the incentive contract inducing the manager to stick to prudent risk management at a minimum cost to bank shareholders?

A contract offered to the manager can be characterized by a triple $\{x_T, R(x), R_T\}$, where $x_T$ denotes a contract termination rule, $R(x) \geq 0$ is an asset-based remuneration defined for each $x \geq x_T$ and $R_T \geq 0$ is a lump-sum terminal pay-off delivered at the contract termination date. I restrict the analysis to the class of affine contracts, looking

[20]For example, under Basel III, dividend restrictions are imposed on the banks that fail to maintain capital conservation buffers.

for asset-based remuneration in the following form:

$$R(x) = w_1 x + w_0, \tag{11}$$

which potentially allows for the variable and fixed compensation components.

Given that materialization of tail risk will make the choice of management technology verifiable ex-post, the contract implies an additional condition: the manager will be fired without any terminal pay if a large loss occurs. The threat of being fired after a large loss represents a maximum feasible punishment under the limited liability of the manager, enabling shareholders to avoid inefficient costs of incentive provision.

Consider the manager's choice between prudent and imprudent risk management. Given any contract $\{x_T, R(x), R_T\}$, the manager maximizes contract continuation value, $W(x)$, which is contingent on bank asset value and represents the current expected value of total future contract payoffs, including any private benefits:

$$\max_{s_\tau \in \{0,1\}} \quad W(x_t) = \mathbb{E}\left[\int_t^{\tau \wedge T} e^{-r(\tau - t)}(R(x_\tau) + (1 - s_\tau) b x_\tau) d\tau + e^{-r(T-t)} R_T\right], \tag{12}$$

where $x_\tau$ follows (1) and $T = \inf\{t \geq 0 : x_t \leq x_T\}$.

By the standard dynamic programming arguments, the optimal contract continuation value satisfies

$$rW(x) = \max_{s \in \{0,1\}} \quad \Big\{\frac{1}{2}\sigma^2 x^2 W''(x) + (\mu - s\Delta\mu)W'(x) + R(x) + (1 - s)(bx - \lambda W(x))\Big\}. \tag{13}$$

As shown by (13), imprudent risk management has an ambiguous effect on the manager's wealth. On the one hand, it boosts contract continuation value by increasing the expected asset return and allowing the manager to collect private benefits. On the other hand, the manager risks losing his position (and, consequently, the expected value of further payoffs) with probability $\lambda dt$ in a short period of time $dt$. As long as the expected loss of contract continuation value under tail-risk exposure, $\lambda W(x)$, exceeds the instantaneous gain from imprudent risk management, $\Delta\mu x W'(x) + bx$, the manager will stick to prudent risk management.

Assume that replacing the manager is costless.[21] Let $(T_m)_{m \geq 1}$ denote the sequence of contract termination dates and let $SC(x_t)$ denote the expected value of the total shareholders' costs of managerial compensation evaluated at time $t$:

$$SC(x_t) = \mathbb{E}\left[\int_t^{+\infty} e^{-r(\tau - t)} R(x_\tau) d\tau + \sum_{m \geq 1} e^{-r(T_m - t)} R_T\right]. \tag{14}$$

[21] Allowing for the cost of managerial turnover would not affect the optimal contract design.

Then, for any $x_t > x_R$, the optimization problem of bank shareholders can be stated as follows:

$$\min_{x_T \geq x_R, w_1, w_0, R_T \geq 0} \quad SC(x)$$

s.t.

$$\lambda W(x) \geq \Delta\mu x W'(x) + bx, \tag{15}$$

$$w_1 x + w_0 \geq 0, \tag{16}$$

$$W(x) \geq 0, \tag{17}$$

where $W(x)$ is given by (12) with $s_\tau = 1$.

Condition (15) is the incentive compatibility constraint resulting from the manager's maximization problem (12). Condition (16) reflects the limited liability of the manager. Finally, condition (17) stands for the individual rationality constraint.

It is shown in Appendix B that the incentive constraint (15) holds for all $x \geq x_R$, if the following condition is satisfied:[22]

$$w_1 \nu(\lambda - \Delta\mu)x \geq bx - \lambda w_0/r, \quad \forall x \geq x_R. \tag{18}$$

Let $w_1^*$ denote the minimum incentive-compatible sensitivity of managerial compensation to the changes of the bank's asset value:

$$w_1^* = \frac{b}{\nu(\lambda - \Delta\mu)}. \tag{19}$$

For any given $w_0$, the minimum shareholders' costs of incentive provision would be ensured by $w_1(w_0)$ that makes constraint (18) binding at $x_R$:

$$w_1(w_0) = w_1^* - \frac{\lambda}{\nu(\lambda - \Delta\mu)} \frac{w_0}{r} \frac{1}{x_R}. \tag{20}$$

It is easy to see that $w_1(w_0) \geq w_1^*$ if and only if $w_0 \leq 0$. Given $w_1(w_0)$ defined by (20), it can be shown that the total expected shareholders' costs of incentive provision are decreasing with $w_0$. Thus, it is optimal to set $w_0 = 0$, keeping compensation sensitivity $w_1$ to a minimum.[23]

To define the optimal termination rule and the optimal terminal payoff, I compare the minimum value of shareholders' costs under two options. The first option implies $x_T = x_R$,

[22] This condition can be interpreted as the incentive compatibility condition (15) rewritten for the perpetual contract continuation value, $w_1\nu + w_0/r$.

[23] Alternatively, one could obtain the same result by considering the minimum incentive-compatible $w_0(w_1)$ as a function of compensation sensitivity $w_1 > w_1^*$ and then minimizing the total shareholders' costs of incentive provision over $w_1$.

so that the manager will be replaced when bank asset value hits the regulatory threshold; the second option implies $x_T = \emptyset$, meaning that the manager will be allowed to keep his position forever if no loss occurs. I show in Appendix B that, faced with termination rule $x_T = x_R$, the manager has to be provided with a strictly positive terminal payoff equal to the expected value of the further contract payoffs he could obtain from continuation; i.e., $R_T = W(x_R)$. Conversely, letting the manager stay forever provided that no loss occurs would allow shareholders to avoid these payments. Put differently, this result suggests that firing the manager when the bank asset value is brought down to the regulatory threshold by volatility risk (and not by a large loss) would be inefficient.[24]

**Proposition 4** *The optimal incentive contract which will induce prudent risk management at minimum cost to shareholders is characterized by incentive remuneration $R^*(x) = w_1^* x$ for all $x \geq x_R$. The manager is never fired provided no loss occurs; i.e., $x_T^* = \emptyset$ and $R_T^* = \emptyset$.*

Under the optimal incentive contract, the manager will stick to prudent risk management and thus will never be forced to step down. Then, the total shareholders' costs of incentive provision will coincide with the minimum incentive-compatible contract continuation value for the manager:

$$SC^*(x) \equiv W^*(x) = w_1^* \nu \left( x + \frac{z x_R}{(1-(1+z)^{\beta_2})} \left( \frac{x}{x_R} \right)^{\beta_2} \right). \tag{21}$$

## 5.2 The optimal incentive capital requirements

Given the optimal incentive contract with the manager, it becomes possible to address the design of capital regulation in the context of the internal agency problem. The regulator is now looking for the optimal regulatory threshold $x_R$, which will induce shareholders to promote prudent risk management in their bank by implementing the optimal incentive compensation contract defined in Proposition 4. Let $E_{W^*}(x)$ denote equity value that accounts for the costs of the optimal incentive compensation:

$$E_{W^*}(x) = E(x) - W^*(x) = \nu(\delta - w_1^*)x - D - \Omega_w(x_R, z)x^{\beta_2}, \tag{22}$$

where

$$\Omega_w(x_R, z) = \left[ \frac{\xi_0 + (1 + \xi_1 - \nu(\delta - w_1^*))z x_R}{1-(1+z)^{\beta_2}} \right] {x_R}^{-\beta_2} > 0.$$

[24] A contract with infinite duration, however, might be inappropriate for the setting in which the manager can control both tail risk exposure and asset volatility. In fact, increasing $\sigma$ in the neighborhood of the regulatory threshold would increase the probability of asset expansion, which would allow the manager to benefit from higher compensation awards. A design of the optimal incentive compensation under such a bi-dimensional moral hazard problem is suggested for further research.

Then, the regulatory problem can be stated as follows:

$$\max_{x_R>0,z>0} \quad E_{W^*}(x) \geq 0 \qquad \text{s.t.}$$

$$\lambda(E_{W^*}(x) - \mathbb{1}_{x\geq x_R/\alpha} E_{W^*}(\alpha x)) \geq \Delta\mu x E'_{W^*}(x) + w_1^* x \quad \text{for } \forall x \geq x_R, \tag{23}$$

where $x$ follows (1) with $s = 1$ and $w_1^*$ is given by (19).

The above problem is similar to the one defined in the benchmark case. The only difference comes from the fact that the real costs of prudent risk management to bank shareholders are amplified by the costs of the incentive compensation which has to be offered to the manager. Then, the optimal regulatory threshold can be obtained in the same way as in the benchmark case. In particular, for any given expansion factor $z$, one can identify the minimum feasible regulatory threshold $x_R^A(z)$ that would preclude imprudent risk management (it results from the binding incentive compatibility constraint of bank shareholders). Next, the optimal asset expansion factor $z^{**} = \arg\min \quad \Omega_w(x_R^A(z), z)$ should be chosen so as to maximize equity value constructed under $x_R^A(z)$. Finally, plugging $z^{**}$ into the expression of $x_R^A(z)$ would yield the value of the optimal incentive-based regulatory threshold. Solving the regulatory problem in this way leads to the following result.

**Proposition 5** *In the presence of the internal agency problem, the regulator can prevent the bank from engaging in tail risk via the optimal regulatory threshold*

$$x_R^A(z^{**}) = \frac{h_0(z^{**})}{h_1(z^{**}) - w_1^* h_2(z^{**})}, \quad \textit{where} \quad h_2(z^{**}) > 0,$$ [25]

*such that the bank will be subject to liquidation if the value of its assets falls below $x_R^A(z^{**})$.*

It is worth noting that the above proposition is relevant if and only if $h_1(z) - w_1^* h_2(z) > 0$, which implies that both the proportional costs of asset expansion and the size-adjusted private benefits that the manager can generate when taking on tail risk have to be relatively low.

In can be easily noticed that, given the same expansion factor $z$, the optimal incentive regulatory threshold obtained under the internal agency problem exceeds that obtained in the benchmark case; i.e., $x_R^A(z) > x_R^B(z)$. This suggests that capital regulation, which does not internalize the costs of the internal agency problem between bank shareholders and bank managers, would be unable to deter banks from engaging in tail risk.[26] Thus,

[25] The expression for $h_2(z)$ is provided in Appendix B.

[26] In the light of this theoretical result, it would be interesting to conduct an empirical investigation of whether the banks facing the same level of capital charges but differing in the degree of the internal agency problem exhibit heterogeneity in the realization of large losses.

the internal agency problem matters and should be taken into account by bank regulators when designing capital regulation.

Solving the above problem numerically shows that the optimal regulatory threshold $x_R^A(z^{**})$ increases with the degree of the internal agency problem reflected by the size-adjusted private benefits $b$ (see Appendix C, Panel C.5). In terms of policy implications, this result suggests that the banks exposed to the more severe internal agency problem related to risk management should be faced with higher minimum capital requirements. Indeed, the more acute is the internal agency problem, the more substantial will be the costs of the incentive contract that must be offered to the manager. This would erode the value of shareholders' claim, thereby, weakening the shareholders' incentives to promote prudent risk-management and to keep the bank operating upon breaching minimum capital requirements. As a result, strengthening capital requirements is needed in order to preserve the incentive mechanism.

# 6 Discussion

This section is devoted to the discussion of several regulatory policy issues aimed at improving the risk-management culture in the banking sector. I start by examining the impact of bonus taxes on risk management. Then I consider the proposals to impose explicit control over managerial compensation. Finally, I discuss the trade-off between capital requirements and insurance protection as a potential risk mitigation tool.

## 6.1 Bonus taxes and risk management

In the aftermath of the 2007-09 financial crisis, several European countries (UK, France, Italy) introduced a tax on the performance bonuses of bank top management. One of the official purposes of this measure was to improve the risk-management culture in the banking sector. The model developed in this paper can be used to examine the effect of bonus taxes on shareholders' incentives to promote prudent risk management in their bank.

Let a tax rate $\tau$ be applied to asset-based incentive compensation $R(x)$. Assume first that taxes are paid by bank shareholders. In this case, bonus taxes have no impact on the manager's incentives, and thus bank shareholders can induce prudent risk management by using the same optimal incentive contract as in a tax-free world. However, the total shareholders' costs of creating incentives will be increased by the amount of taxes and will be equal to $(1+\tau)W^*(x)$, where $W^*(x)$ is defined by (21). Consider now the alternative setting, where bonus taxes are paid by the bank manager. To be motivated to stick to prudent risk management, the manager should have at least the same level of wealth after the tax levy as in a tax-free world. Then, the minimum incentive contract continuation value that should be offered to the manager will be given by $1/(1-\tau)W^*(x)$.

The first conclusion that can be drawn from this analysis is that bonus taxes are inappropriate for dealing with excessive risk-taking in banks. Under both scenarios, they increase the real shareholders' costs of promoting prudent risk management and thus would lead to a situation requiring tougher capital regulation. It is also easy to see that total shareholders' costs of creating incentives when bonus taxes are paid by the manager would be higher than when bonus taxes are paid by the shareholders themselves. Thus, the lesser of two evils would be to collect bonus taxes from bank shareholders rather than from bank managers, which is consistent with the practices adopted in UK and France in 2009-2010.

## 6.2 Implicit *vs* explicit regulation of managerial pay

Following the recent empirical evidence suggesting that, in the years preceding the 2007-2009 financial crisis, the existing compensation schemes exacerbated risk-taking incentives in the banking sector,[27] certain academic studies, such as Bebchuk and Spamann (2010) and Bolton, Mehran and Shapiro (2010), advocate for introducing regulatory control over executive compensation. However, exercising *explicit* control over executive compensation might be problematic. The first problem is that regulators do not dispose of all of the information needed for the efficient design and enforcement of executive compensation. Second, it is still unclear what form the optimal incentive compensation structure should take. Finally, experience shows that economic agents always find a way to get around regulations if their incentives diverge from regulatory purposes. Given that shareholders originally have higher risk appetite than managers, explicitly regulating executive pay without regulating shareholders' incentives would probably be a waste of regulatory resources. These reasons argue for *implicit* control over managerial incentives. The detailed design of managerial compensation should be left to bank shareholders, whereas the role of the bank regulator is to ensure that shareholders have sufficient incentives to pay due attention to the quality of risk management in their banks.

## 6.3 Insurance policy and capital requirements

The last relevant question I discuss here is whether capital requirements should be reduced if a bank acquires an insurance policy against tail risk. Actually, only the advanced approach of the Basel capital regulation framework considers an insurance policy

[27]See e.g. Chen et al. (2006), Cheng et al. (2010), DeYoung et al. (2013).

as a risk mitigation tool and authorizes banks holding such policies to operate with reduced mandatory capital. However, it seems that greater reliance on insurance protection may aggravate the problem of moral hazard. The point is that an insurance policy allows banks to transfer risk without tackling it at the source; i.e., it helps to reallocate risks but it cannot prevent their accumulation within the financial system. Moreover, in the context of a systemic crisis, insurance companies themselves may experience serious financial problems, being therefore unable to provide loss coverage.[28] Thus, even though recourse to insurance may be beneficial for bank shareholders (i.e. it might be cheaper to buy an insurance policy than to create appropriate incentives for the manager), prudent risk management would be the only durable solution from the perspective of social welfare. Banks can be allowed to buy insurance protection against some external risks such as external fraud, hacking attacks, and natural disasters, since insurance protection will not promote moral hazard and risk accumulation in this case. At the same time, regulators should induce banks to tackle the sources of internal risk. As shown in this paper, this can be realized by means of the incentive-based capital requirements which internalize the optimal recapitalization decisions of bank shareholders as well as the costs of resolving the internal agency problem.

# 7 Conclusion

This paper attempts to rethink the approach to bank capital regulation in response to the huge incentive distortions revealed by the 2007-09 financial crisis. The incentive-based design of capital requirements proposed here is aimed at dealing with "manufactured" tail risk in the banking sector. This paper shows how to design capital requirements which would induce bank shareholders to care about the quality of risk management in their banks and put in place an incentive compensation scheme that will deter bank managers from engaging in tail risk.

Two features are crucial for the design of capital requirements to produce the required incentive effect. First, since merely increasing capital requirements may not prevent banks from engaging in tail risk, capital regulation should be designed in such a way so as to induce bank shareholders to undertake costly asset expansions in order to comply with minimum capital requirements. The choice of making bank shareholders bear the private costs of compliance with capital regulation appears to be crucial for giving them incentives to pay attention to risk management strategies adopted by the management. Second, the design of minimum capital requirements should account for the internal

[28] This happened to AIG, one of the biggest players on the world insurance market, which was bailed out by the Federal Reserve Bank and the U.S. Treasury in 2008.

agency problem between bank shareholders and bank managers. Since the internal agency problem makes it costly for bank shareholders to promote prudent risk-taking behavior by bank managers, bank shareholders should be required to maintain a larger stake in the game. This might be viewed as justification for more stringent capital requirements for systemically important banks, which typically exhibit both severe agency problems and higher propensity to manufacture tail risk. Overall, the proposed approach to bank capital regulation would help to avoid costly bank liquidations, removing the incentives for "manufacturing" tail risk. Moreover, it would allow bank regulators to implicitly control the risk-taking incentives of bank top managers without exercising direct control over managerial compensation.

# Appendix A. Valuation of contingent claims

## A.1. Equity value in the benchmark case

Let $x_R$ be any arbitrary regulatory threshold. Let $(\tau_n)_{n\geq 1}$ denote the sequence of asset expansion dates. Under conjecture that shareholders will raise equity and expand assets only when the bank asset value attains the regulatory threshold, the cumulated value of the total shareholders' costs of asset expansions at time $t$ will be given as follows:

$$I_t = ((1+\xi_1)zx_R + \xi_0)\sum_{n\geq 1} \mathbb{1}_{\tau_n \leq t}, \tag{A1}$$

where $(\tau_n)_{n\geq 1}$ denotes the sequence of asset expansion dates.

Equity value in the absence of the internal agency problem is given by

$$E(x_t) = \mathbb{E}\left[\int_t^{+\infty} e^{-r(\tau-t)}(\delta x_\tau - rD)d\tau - \int_t^{+\infty} e^{-r(\tau-t)} dI_\tau\right]. \tag{A2}$$

Solving the corresponding ODE

$$1/2\sigma^2 x^2 E''(x) + (\mu - \Delta\mu)xE'(x) - rE(x) + \delta x - rD = 0 \tag{A3}$$

subject to boundary condition

$$E(x_R) = E((1+z)x_R) - (1+\xi_1)zx_R - \xi_0 \tag{A4}$$

yields:

$$E(x) = \nu\delta x - D - \Omega(x_R, z)x^{\beta_2}, \tag{A5}$$

where $\nu = (r - \mu + \Delta\mu)^{-1}$, $\beta_2 < 0$ is the negative root of the characteristic equation

$$1/2\sigma^2\beta(\beta-1) + (\mu - \Delta\mu)\beta = r, \tag{A6}$$

and

$$\Omega(x_R, z) = \left[\frac{\xi_0 + (1+\xi_1 - \nu\delta)zx_R}{1-(1+z)^{\beta_2}}\right] {x_R}^{-\beta_2} > 0. \tag{A7}$$

## A.2. Equity value under the optimal incentive contract

Given the optimal incentive contract defined in Proposition 4, bank equity value follows

$$E_{W^*}(x_t) = \mathbb{E}\left[\int_t^{+\infty} e^{-r(\tau-t)}((\delta - w_1^*)x_\tau - rD)d\tau - \int_t^{+\infty} e^{-r(\tau-t)} dI_\tau\right], \tag{A8}$$

where

$$w_1^* = \frac{b}{\nu(\lambda - \Delta\mu)}. \tag{A9}$$

Solving the corresponding ODE

$$1/2\sigma^2 x^2 E''_{W^*}(x) + (\mu - \Delta\mu)xE'_{W^*}(x) - rE_{W^*}(x) + (\delta - w_1^*)x - rD = 0 \tag{A10}$$

subject to boundary condition

$$E_{W^*}(x_R) = E_{W^*}((1+z)x_R) - (1+\xi_1)zx_R - \xi_0 \tag{A11}$$

yields:

$$E_{W^*}(x) = \nu(\delta - w_1^*)x - D - \Omega_w(x_R, z)x^{\beta_2}, \tag{A12}$$

where

$$\Omega_w(x_R, z) = \left[\frac{\xi_0 + (1+\xi_1 - \nu(\delta - w_1^*))zx_R}{1-(1+z)^{\beta_2}}\right] {x_R}^{-\beta_2} > 0. \tag{A13}$$

Let $W^*(x)$ denote the total shareholders' costs of the optimal incentive compensation contract:

$$W^*(x) = w_1^*\nu\left(x + \frac{zx_R}{(1-(1+z)^{\beta_2})}\left(\frac{x}{x_R}\right)^{\beta_2}\right). \tag{A14}$$

Then, equity value in the presence of the internal agency problem can be rewritten as follows:

$$E_{W^*}(x) = E(x) - W^*(x), \tag{A15}$$

where $E(x)$ is defined by (A5).

# Appendix B. Proofs

**Proof of Proposition 1.** Consider the optimal strategy of bank shareholders when there is neither the internal agency problem nor capital regulation. Since $\delta + (\mu - \Delta\mu) < r$, shareholders will never expand bank assets on their own and will close the bank at some liquidation threshold that maximizes equity value. For any given liquidation threshold $x_L$, implementing prudent risk management is optimal as long as:

$$\lambda(E(x) - \mathbb{1}_{x \geq x_L/\alpha}E(\alpha x)) \geq \Delta\mu x E'(x). \tag{B1}$$

Assume that condition (B1) always holds for any $x \geq x_L$. Then, bank equity value would follow:

$$E(x) = (D - \nu\delta x_L)\left(\frac{x}{x_L}\right)^{\beta_2} + \nu\delta x - D, \tag{B2}$$

where $\beta_2 < 0$ is a negative root of (A6).

The optimal liquidation threshold, $x_L^*$, maximizing equity value, will be given by the standard formula:

$$x_L^* = \frac{\beta_2}{\beta_2 - 1}\frac{D}{\nu\delta}. \tag{B3}$$

Then, for $x \in [x_L^*, x_L^*/\alpha)$, the incentive compatibility condition (B1) can be rewritten as follows:

$$(\lambda - \beta_2\Delta\mu)(D - \nu\delta x_L^*)\left(\frac{x}{x_L^*}\right)^{\beta_2} + (\lambda - \Delta\mu)\nu\delta x - \lambda D \geq 0. \tag{B4}$$

Note that condition (B4) is binding for $x = x_L^*$. Since the first term on its left-hand side is a decreasing and convex function of $x$, condition (B4) does not hold in the neighborhood of $x_L^*$. Thus, in the absence of any regulation, sticking *forever* to prudent risk management is *never* optimal.□

**Proof of Proposition 2.** Assume that asset expansions are prohibitively costly. Consider any regulatory liquidation threshold $x_L \geq x_L^*$. Assume that the bank would stick to prudent risk management for all $x \geq x_L$. Then, bank equity value would be defined by (B2) and, for $x \in [x_L, x_L/\alpha)$, the incentive compatibility condition (B1) can be rewritten as follows:

$$(\lambda - \beta_2 \Delta\mu)\left(D - \nu\delta x_L\right)\left(\frac{x}{x_L}\right)^{\beta_2} + (\lambda - \Delta\mu)\nu\delta x - \lambda D \geq 0. \tag{B5}$$

In the case when $x_L = x_L^*$, condition (B5) does not hold when $x \to x_L^*$ (see the Proof of Proposition 1). Consider the case when $x_L > x_L^*$. Let $f(x)$ denote the left-hand side of (B5). For all $x_L > x_L^*$, it follows that:

$$\lim_{x \to x_L} f(x) = \Delta\mu(\nu\delta(\beta_2 - 1)x_L - \beta_2 D) < 0. \tag{B6}$$

Therefore, any regulatory liquidation threshold $x_L \geq x_L^*$ would be unable to prevent the bank from engaging in tail risk.□

**Proof of Proposition 3.** Consider the regulatory problem in the case of the owner-managed bank:

$$\max_{x_R > 0, z > 0} \quad E(x_0) \geq 0 \quad \text{s.t.}$$

$$\lambda(E(x) - \mathbb{1}_{x \geq x_R/\alpha} E(\alpha x)) \geq \Delta\mu x E'(x) \quad \text{for } \forall x \geq x_R,$$

where $x_0 > x_R$ and $E(x)$ is given by (A5).

For any expansion factor $z > 0$, consider a minimum incentive-compatible regulatory threshold $x_R^B(z)$ that makes the incentive compatibility condition binding at $x = x_R$:

$$x_R^B(z) = h_0(z)/h_1(z), \tag{B7}$$

where

$$h_0(z) = (1 - (1+z)^{\beta_2})\lambda D + \xi_0(\lambda - \beta_2\Delta\mu), \tag{B8}$$

and

$$h_1(z) = (1 - (1+z)^{\beta_2})(\lambda - \Delta\mu)\nu\delta - (1 + \xi_1 - \nu\delta)(\lambda - \beta_2\Delta\mu)z > 0. \tag{B9}$$

It is shown below that the pair $z^* = \arg\min \Omega(x_R^B(z), z)$ and $x_R^B(z^*)$ is a solution to the above maximization problem.

***Incentive compatibility.*** For any arbitrary expansion factor $z > 0$, it must be verified that $x_R^B(z)$ ensures the incentive constraint of bank shareholders for all $x \geq x_R^B(z)$. Plugging equity value (A5) into the incentive compatibility constraint defined in the region

$[x_R^B(z), x_R^B(z)/\alpha)$ yields:

$$-(\lambda-\beta_2\Delta\mu)\left(\frac{\xi_0+(1+\xi_1-\nu\delta)zx_R^B(z)}{1-(1+z)^{\beta_2}}\right)\left(\frac{x}{x_R^B(z)}\right)^{\beta_2}+(\lambda-\Delta\mu)\nu\delta x-\lambda D\geq 0. \quad \text{(B10)}$$

Since the above condition is binding at $x = x_R^B(z)$ and its left-hand side is increasing with $x$, it holds for all $x \in [x_R^B(z), x_R^B(z)/\alpha)$. For $x \geq x_R^B(z)/\alpha$, the incentive compatibility constraint of bank shareholders transforms to:

$$-(\lambda(1-\alpha^{\beta_2})-\beta_2\Delta\mu)\left(\frac{\xi_0+(1+\xi_1-\nu\delta)zx_R^B(z)}{1-(1+z)^{\beta_2}}\right)\left(\frac{x}{x_R^B(z)}\right)^{\beta_2}+(\lambda(1-\alpha)-\Delta\mu)\nu\delta x\geq 0. \quad \text{(B11)}$$

To show that condition (B11) holds for any $x \geq x_R^B(z)/\alpha$, I make use of the following lemma:

**Lemma 1** *For $\beta_2 < 0$, $\alpha \in (0,1)$ and $\Delta\mu < \lambda(1-\alpha)$, one has $\lambda(1-\alpha^{\beta_2}) - \beta_2\Delta\mu < 0$.*

**Proof of Lemma 1.** Given $\Delta\mu < \lambda(1-\alpha)$ and $\beta_2 < 0$, it follows that $\lambda(1-\alpha^{\beta_2}) - \beta_2\Delta\mu < \lambda(1-\alpha^{\beta_2}) - \beta_2\lambda(1-\alpha) \equiv f(\alpha)$. Since $f(1) = 0$ and $f'(\alpha) = \beta_2\lambda(1-\alpha^{\beta_2-1}) > 0$ for $\alpha \in (0,1)$, it follows that $f(\alpha) < 0$ for $\alpha \in (0,1)$. Hence, $\lambda(1-\alpha^{\beta_2}) - \beta_2\Delta\mu < 0$.$\square$

By Lemma 1, $\lambda(1-\alpha^{\beta_2}) - \beta_2\Delta\mu < 0$, and $\Delta\mu < \lambda(1-\alpha)$ by the initial assumption. Therefore, (B11) holds for all $x \geq x_R^B(z)/\alpha$.

***Feasibility.*** Note that $x_R^B(z) > 0$ if and only if $h_1(z) > 0$, which can be rewritten as the constraint on the maximum feasible value of the proportional costs of asset expansion:

$$\xi_1 < \overline{\xi}_1(z), \quad \text{(B12)}$$

where

$$\overline{\xi}_1(z) = \nu\delta\left[\left(\frac{1-(1+z)^{\beta_2}}{z}\right)\left(\frac{\lambda-\Delta\mu}{\lambda-\beta_2\Delta\mu}\right)+1\right]-1. \quad \text{(B13)}$$

Now, it must be verified that (i) equity value at the regulatory threshold is strictly positive, so that it is optimal to raise new equity capital and to expand bank assets at $x_R^B(s)$, rather than to prefer regulatory liquidation; (ii) given $x_R^B(z)$, asset expansion at any $x > x_R^B(z)$ would be suboptimal.

First, I check that $E(x_R^B(z)) > 0$. By using the expression of $E(x)$, one can easily show that $E(x_R) > 0$ for any $x_R > x_R^*(z)$, where $x_R^*(z)$ is a critical asset expansion trigger such that $E(x_R^*(z)) = 0$:

$$x_R^*(z) = \frac{(1-(1+z)^{\beta_2})D+\xi_0}{(1-(1+z)^{\beta_2})\nu\delta-(1+\xi_1-\nu\delta)z} > D. \quad \text{(B14)}$$

By simultaneously multiplying both the numerator and denominator of $x_R^*(z)$ by $\lambda$, one may check that $x_R^B(z) > x_R^*(z)$. Therefore, $E(x_R^B(z)) > 0$.

In order to show that asset expansion at any $x > x_R^B(z)$ would be suboptimal, it suffices to verify the following condition for $x > x_R^B(z)$:

$$E((1+z)x) - E(x) - (1+\xi_1)zx - \xi_0 < 0. \quad \text{(B15)}$$

Let $g(x)$ denote the left-hand side of the above inequality. Since $g'(x) < 0$, $g''(x) > 0$ and $g(x_R^B(z)) = 0$, inequality (B15) holds for $\forall x > x_R^B(z)$.

***Optimality.*** Since $\frac{\partial E(x)}{\partial x_R} < 0$, the minimum incentive compatible regulatory threshold $x_R^B(z)$ is optimal for any given $z > 0$. Then, the solution of the maximization problem will be delivered by $z^* = \arg\max\ E(x|x_R^B(z)) \equiv \arg\min\ \Omega(x_R^B(z), z)$.□

**Proof of Proposition 4.** Assume there exists some incentive regulatory threshold $x_R$, such that shareholders want to promote prudent risk management in their bank for $\forall x \geq x_R$. Then, the shareholders' maximization problem is reduced to minimization of the total expected costs of incentive managerial compensation:

$$\min_{x_T \geq x_R, w_1, w_0, R_T \geq 0} \quad SC(x_t) = \mathbb{E}\left[\int_t^{+\infty} e^{-r(\tau-t)} R(x_\tau) d\tau + \sum_{m\geq 1} e^{-r(T_m - t)} R_T\right]$$

s.t.

$$\lambda W(x) \geq \Delta\mu x W'(x) + bx, \quad x \geq x_R, \tag{B16}$$

where

$$w_1 x + w_0 \geq 0, \quad x \geq x_R, \tag{B17}$$

and

$$W(x_t) = \mathbb{E}\left[\int_t^{\tau\wedge\tau_T} e^{-r(\tau-t)} R(x_\tau) d\tau + e^{-r(\tau_T - t)} R_T\right] \geq 0. \tag{B18}$$

Assume that the manager is provided with the incentives to stick to prudent risk management. Then, contract continuation value $W(x)$ will follow ODE:

$$1/2\sigma^2 x^2 W''(x) + (\mu - \Delta\mu) x W'(x) - rW(x) + w_1 x + w_0 = 0. \tag{B19}$$

Under the no-bubble condition $\lim_{x\to\infty} W(x) = w_1 x + w_0$, a general solution to (B19) is given by:

$$W(x) = C_0 x^{\beta_2} + w_1 \nu x + \frac{w_0}{r}, \tag{B20}$$

where $C_0$ is any constant defined by the boundary condition at $x_T$.

Consider two alternative cases: $x_T = x_R$ and $x_T = \emptyset$.

**1) Case 1:** $x_T = x_R$. Let $R_T \geq 0$ be any arbitrary terminal payoff. Then, given the boundary condition $W(x_R) = R_T$, the general solution to (B19) can be rewritten as follows:

$$W(x) = w_1 \nu x + \frac{w_0}{r} + \left(R_T - w_1 \nu x_R - \frac{w_0}{r}\right)\left(\frac{x}{x_R}\right)^{\beta_2}. \tag{B21}$$

The boundary condition for the value of the total shareholders' costs will be given by:

$$SC(x_R) = SC((1+z)x_R) + R_T. \tag{B22}$$

Then, the shareholders' optimization problem can be rewritten as follows:

$$\min_{w_0,w_1,R_T} \quad SC_{x_T=x_R}(x) = \left\{ w_1\nu x + \frac{w_0}{r} + \left(\frac{R_T + w_1\nu z x_R}{1-(1+z)^{\beta_2}}\right)\left(\frac{x}{x_R}\right)^{\beta_2} \right\}$$

s.t.

$$(\lambda - \Delta\mu\beta_2)\left(R_T - w_1\nu x_R - \frac{w_0}{r}\right)\left(\frac{x}{x_R}\right)^{\beta_2} + w_1\nu(\lambda-\Delta\mu)x + \lambda\frac{w_0}{r} \geq bx, \quad x \geq x_R, \quad \text{(B23)}$$

$$w_1 x + w_0 \geq 0, \quad x \geq x_R. \quad \text{(B24)}$$

For any $w_1$ and $w_0$, the optimal terminal payoff is given by:

$$R_T^* = w_1\nu x_R + \frac{w_0}{r}. \quad \text{(B25)}$$

Indeed, any $R_T > R_T^*$ would inefficiently increase $SC_{x_T=x_R}(x)$, whereas for any $R_T < R_T^*$ incentive compatibility condition (B23) cannot be ensured for $\forall x \geq x_R$.

Given $R_T^*$ defined by (B25), incentive constraint (B23) transforms to:

$$w_1\nu(\lambda-\Delta\mu)x + \lambda\frac{w_0}{r} - bx \geq 0, \quad x \geq x_R. \quad \text{(B26)}$$

To ensure that (B26) holds for $\forall x \geq x_R$, the first derivative of the left-hand side of (B26) must be positive, which reduces the choice of $w_1$ to the subset:

$$w_1 \geq \frac{b}{\nu(\lambda-\Delta\mu)} \equiv \widehat{w}_1. \quad \text{(B27)}$$

For any given $w_0$, the minimum incentive-compatible $w_1$ will be provided by the binding incentive compatibility condition (B26) evaluated at $x = x_R$. In particular,

$$w_1(w_0) = \widehat{w}_1 - \frac{\lambda}{\nu(\lambda-\Delta\mu)}\frac{w_0}{r}\frac{1}{x_R}. \quad \text{(B28)}$$

Note that $w_1(w_0) \geq \widehat{w}_1$ if and only if $w_0 \leq 0$. Combining this constraint with that corresponding to the limited liability constraint (B17) yields the following set of feasible $w_0$:

$$\Theta = \left\{ w_0 \in \left[-\frac{bx_R}{\nu(\lambda-\Delta\mu)-\lambda/r}, 0\right] \right\}, \quad \text{(B29)}$$

if $\Delta\mu/\mu < \lambda/(r+\lambda)$ and

$$\Theta = \{w_0 \leq 0\}, \quad \text{(B30)}$$

if $\Delta\mu/\mu > \lambda/(r+\lambda)$.

Then, the shareholders' cost-minimization problem takes the following form:

$$\min_{w_0\in\Theta} \quad SC_{x_T=x_R}(x) = \left\{ w_1(w_0)\nu x + \frac{w_0}{r} + \left(\frac{\frac{w_0}{r} + w_1(w_0)\nu(1+z)x_R}{1-(1+z)^{\beta_2}}\right)\left(\frac{x}{x_R}\right)^{\beta_2} \right\},$$

where $w_1(w_0)$ is given by (B28).

Taking the first derivative of $SC_{x_T=x_R}(x)$ with respect to $w_0$ yields:

$$\frac{\partial SC_{x_T=x_R}(x)}{\partial w_0} = \frac{1}{r}\left[\underbrace{1-\frac{\lambda}{\lambda-\Delta\mu}\frac{x}{x_R}}_{<0}+\underbrace{\frac{1}{(1-(1+z)^{\beta_2})}}_{>0}\underbrace{\left(1-\frac{\lambda(1+z)}{\lambda-\Delta\mu}\right)}_{<0}\left(\frac{x}{x_R}\right)^{\beta_2}\right]<0. \tag{B31}$$

Therefore, $w_0^* = 0$ and $w_1^* = \widehat{w}_1$. The total expected costs of incentive managerial compensation are given by:

$$SC^*_{x_T=x_R}(x) = w_1^*\nu\left(x+\frac{(1+z)x_R}{(1-(1+z)^{\beta_2})}\left(\frac{x}{x_R}\right)^{\beta_2}\right). \tag{B32}$$

**2) Case 2:** $x_T = \emptyset$. Note that, in this case, $R_T = \emptyset$ and $SC(x) = W(x)$, so that the shareholders' optimization problem takes the following form:

$$\min_{w_0,w_1} \; SC_{x_T=\emptyset}(x) = \left\{w_1\nu x+\frac{w_0}{r}+\frac{w_1\nu z x_R}{(1-(1+z)^{\beta_2})}\left(\frac{x}{x_R}\right)^{\beta_2}\right\}$$

s.t.

$$(\lambda-\Delta\mu\beta_2)\frac{w_1\nu z x_R}{(1-(1+z)^{\beta_2})}\left(\frac{x}{x_R}\right)^{\beta_2}+w_1(\lambda-\Delta\mu)\nu x+\lambda\frac{w_0}{r}\geq bx, \quad x\geq x_R, \tag{B33}$$

$$w_1x+w_0\geq 0, \quad x\geq x_R. \tag{B34}$$

The necessary condition ensuring that (B33) holds for $\forall x \geq x_R$ is equivalent to (B26). Then, for any given $w_0$, the minimum incentive-compatible $w_1(w_0)$ will be provided by (B28). Inserting (B28) into $SC_{x_T=\emptyset}(x)$ and taking the first derivative with respect to $w_0$ yields:

$$\frac{\partial SC_{x_T=\emptyset}(x)}{\partial w_0} = \frac{1}{r}\left[\underbrace{1-\frac{\lambda}{\lambda-\Delta\mu}\frac{x}{x_R}}_{<0}-\underbrace{\frac{z}{(1-(1+z)^{\beta_2})}}_{>0}\underbrace{\left(\frac{\lambda}{\lambda-\Delta\mu}\right)}_{>0}\left(\frac{x}{x_R}\right)^{\beta_2}\right]<0. \tag{B35}$$

Hence, as in the Case 1, the solution of the above program will be provided by $w_0^* = 0$ and $w_1^* = \widehat{w}_1$. The corresponding value of shareholders' costs is given by:

$$SC^*_{x_T=\emptyset}(x) = w_1^*\nu\left(x+\frac{z x_R}{(1-(1+z)^{\beta_2})}\left(\frac{x}{x_R}\right)^{\beta_2}\right)\equiv W^*(x). \tag{B36}$$

Since $SC^*_{x_T=\emptyset}(x) < SC^*_{x_T=x_R}(x)$ for $\forall x \geq x_R$, the optimal incentive-compatible contract will be defined by the triplet $\{x_T^* = \emptyset, R^*(x) = w_1^*x, R_T^* = \emptyset\}$. □

**Proof of Proposition 5.** Given the optimal incentive contract defined by Proposition 4, the regulatory problem in the context of the internal agency problem can be stated as follows:

$$\max_{x_R>0,z>0} \quad E_{W^*}(x_0) \geq 0 \text{ s.t.}$$

$$\lambda(E_{W^*}(x) - \mathbb{1}_{x\geq x_R/\alpha}E_{W^*}(\alpha x)) \geq \Delta\mu x E'_{W^*}(x) + R^*(x) \quad \text{for } \forall x \geq x_R,$$

where $x_0 > x_R$ and $E_{W^*}(x)$ is given by (A12).

For any expansion factor $z > 0$, consider a minimum incentive regulatory threshold $x_R^A(z)$ such that the incentive compatibility condition holds for $x = x_R$:

$$x_R^A(z) = h_0(z)/(h_1(z) - w_1^* h_2(z)) > 0, \tag{B37}$$

where $h_0(z)$, $h_1(z)$ are given by (B8), (B9) respectively and

$$h_2(z) = \nu((1-(1+z)^{\beta_2})(\lambda - \Delta\mu) + (\lambda - \beta_2\Delta\mu)z). \tag{B38}$$

It is shown below that the pair $z^{**} = \arg\min \Omega_w(x_R^A(z), z)$ and $x_R^A(z^{**})$ is a solution to the above maximization problem.

***Incentive compatibility.*** For any arbitrary expansion factor $z > 0$, regulatory threshold $x_R^A(z)$ must ensure the incentive constraint of bank shareholders for all $x \geq x_R^A(z)$. Let $\delta^* = \delta - w_1^* > 0$.[29] Plugging equity value (A12) into the incentive compatibility condition yields:

$$-(\lambda - \beta_2\Delta\mu)\left(\frac{\xi_0 + (1+\xi_1 - \nu\delta^*)zx_R^A(z)}{1-(1+z)^{\beta_2}}\right)\left(\frac{x}{x_R^A(z)}\right)^{\beta_2} + (\lambda - \Delta\mu)\nu\delta^* x \geq \lambda D, \tag{B39}$$

when $x \in [x_R^A(s), x_R^A(s)/\alpha)$ and

$$-(\lambda(1-\alpha^{\beta_2})-\beta_2\Delta\mu)\left(\frac{\xi_0 + (1+\xi_1 - \nu\delta^*)zx_R^A(z)}{1-(1+z)^{\beta_2}}\right)\left(\frac{x}{x_R^A(z)}\right)^{\beta_2} + (\lambda(1-\alpha)-\Delta\mu)\nu\delta^* x \geq 0, \tag{B40}$$

when $x \geq x_R^A(z)/\alpha$.

Since condition (B39) is binding at $x = x_R^A(z)$ and its left-hand side is increasing on $x$, it holds for all $x \in [x_R^A(z), x_R^A(z)/\alpha)$. Condition (B40) holds for all $x \geq x_R^A(z)/\alpha$ due to Lemma 1 and the initial assumption $\Delta\mu < \lambda(1-\alpha)$.

***Feasibility.*** Note that $x_R^A(z) > 0$ if and only if $h_1(z) > 0$ and $h_1(z) - w_1^* h_2(z) > 0$. Condition $h_1(z) > 0$ translates into the constraint on the maximum level of the proportional costs of asset expansion (see (B12) in the proof of Proposition 3). Condition $h_1(z) - w_1^* h_2(z) > 0$ translates into the constraint on the maximum value of the size-adjusted private benefits:

$$b < \bar{b}(z, \xi_1), \tag{B41}$$

where

$$\bar{b}(z,\xi_1) = (\lambda - \Delta\mu)\nu\left(\delta - \frac{(1+\xi_1)(\lambda - \beta_2\Delta\mu)z}{h_2(z)}\right). \tag{B42}$$

[29]It is shown below that $\delta^* > 0$ when the size-adjusted private benefits $b$ are relatively low.

It is easy to see that condition (B41) implies $w_1^* < \delta$.

It should also be verified that (i) equity value is strictly positive at the regulatory threshold, i.e., $E_{W^*}(x_R^A(z)) > 0$; (ii) given $x_R^A(z)$, expanding bank assets at any $x > x_R^A(z)$ would be suboptimal.

To check that $E_{W^*}(x_R^A(z)) > 0$, note that $E_{W^*}(x_R) > 0$ holds for $x_R > x_R^{**}(z)$, where $x_R^{**}(z)$ is a critical asset expansion trigger such that $E_{W^*}(x_R^{**}(z)) = 0$:

$$x_R^{**}(z) = \frac{(1-(1+z)^{\beta_2})D + \xi_0}{(1-(1+z)^{\beta_2})\nu\delta^* - (1+\xi_1-\nu\delta^*)z} > D, \tag{B43}$$

where $\delta^* \equiv \delta - w_1^*$.

It can be shown that $x_R^A(z) > x_R^{**}(z)$, so that $E_{W^*}(x_R^A(z)) > 0$.

To be sure that, when faced with $x_R^A(z)$, shareholders will not undertake asset expansion at any $x > x_R^A(z)$, it suffices to show that:

$$E_{W^*}((1+z)x) - E_{W^*}(x) - (1+\xi_1)zx - \xi_0 < 0. \tag{B44}$$

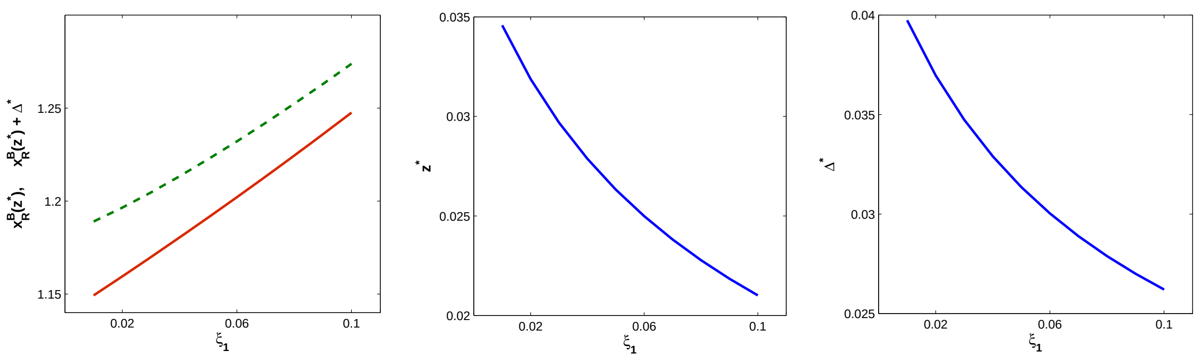
Let $g_{W^*}(x)$ denote the left-hand side of the above inequality. Since $g'_{W^*}(x) < 0$, $g''_{W^*}(x) > 0$ and $g_{W^*}(x_R^A(z)) = 0$, condition (B44) holds for all $x > x_R^A(z)$.

***Optimality.*** Since $E_{W^*}(x)$ is decreasing with $x_R$, the incentive-compatible regulatory threshold $x_R^A(z)$ is optimal for any $z > 0$. Then, the choice $z^{**} = \arg\max\ E_{W^*}(x|x_R^A(z)) \equiv \arg\min\ \Omega_w(x_R^A(z), z)$ completes the solution to the maximization problem.$\square$

# Appendix C. Comparative statics

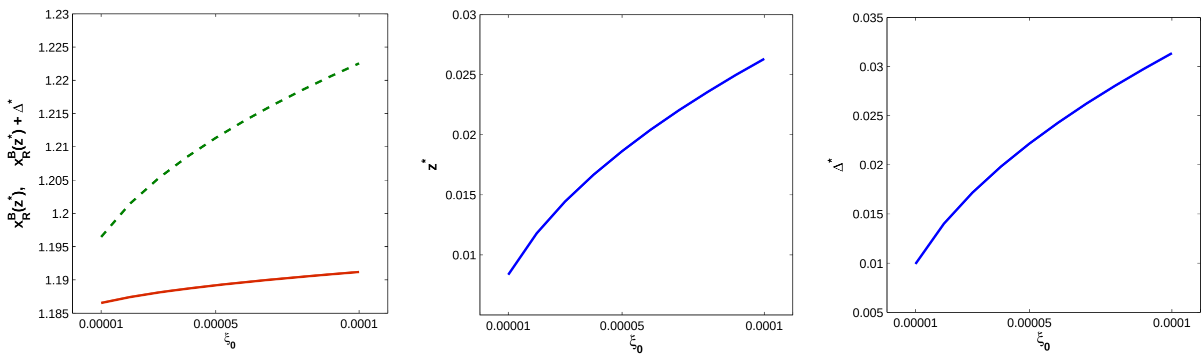
The five following panels contain comparative statics results illustrating the impact of the bank's characteristics on the level of the incentive-based capital requirements and the bank's asset expansion strategy. The first graph in each panel depicts the optimal incentive regulatory threshold (a solid line) and bank asset value after asset expansion (a dashed line). The second graph displays the optimal expansion factor. The third graph shows the pattern of the optimal scale of asset expansion denoted by $\Delta^* \equiv z^* x_R^B(z^*)$ when $b = 0$ or $\Delta^{**} \equiv z^{**} x_R^A(z^{**})$ when $b > 0$. Parameter values common to all comparative statics scenarios are: $D = 1$, $r = 4\%$, $\alpha = 0.9$, $\mu = 2.5\%$, $\Delta\mu = 0.5\%$ and $\delta = 1.9\%$.

*Panel C.1. The impact of the proportional costs of asset expansions*



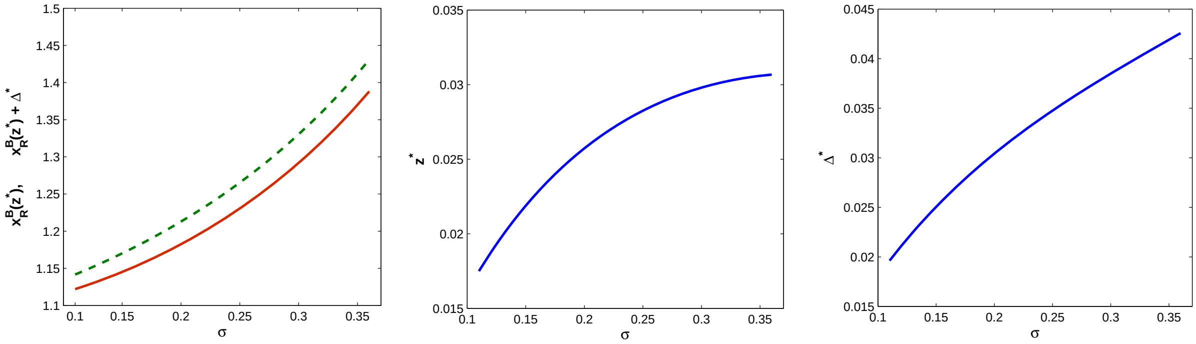

Panel C.1 illustrates the impact of the proportional costs of asset expansion $\xi_1$ on the optimal asset expansion policy in the benchmark case, where $\xi_0 = 0.0001$, $\lambda = 0.15$, $\sigma = 20\%$, $b = 0$.

*Panel C.2. The impact of the fixed costs of asset expansions*



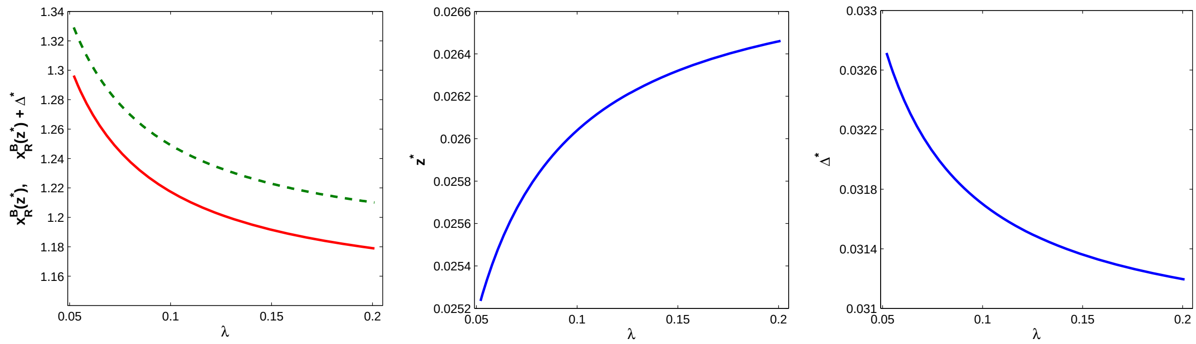

Panel C.2 illustrates the impact of the fixed costs of asset expansion $\xi_0$ on the optimal asset expansion policy in the benchmark case, where $\xi_1 = 0.05$, $\lambda = 0.15$, $\sigma = 20\%$, $b = 0$.

## *Panel C.3. The impact of the asset return volatility*



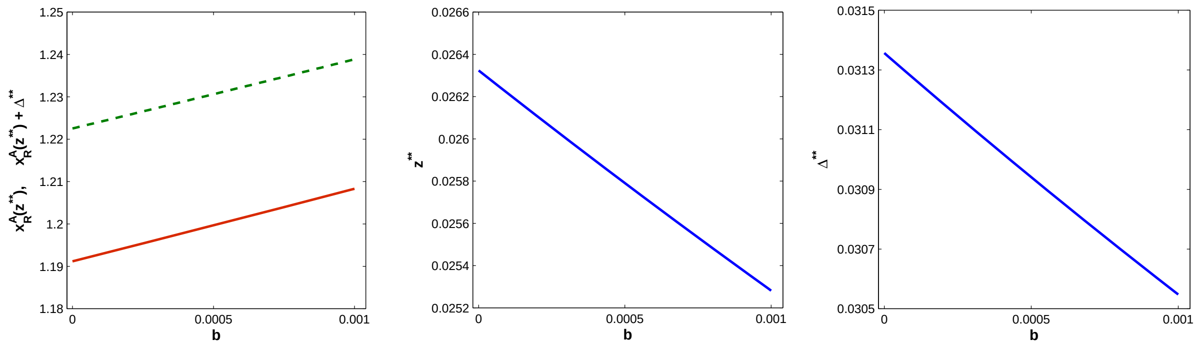

Panel C.3 illustrates the impact of the asset return volatility $\sigma$ on the optimal asset expansion policy in the benchmark case, where $\xi_0 = 0.0001$, $\xi_1 = 0.05$, $\lambda = 0.15$, $b = 0$.

## *Panel C.4. The impact of loss intensity*




Panel C.4 illustrates the impact of loss intensity $\lambda$ on the optimal asset expansion policy in the benchmark case, where $\xi_0 = 0.0001$, $\xi_1 = 0.05$, $\sigma = 20\%$, $b = 0$.

## *Panel C.5. The impact of the internal agency problem*




Panel C.5 illustrates the impact of the size-adjusted private benefits $b$ on the optimal asset expansion policy, where $\xi_0 = 0.0001$, $\xi_1 = 0.05$, $\lambda = 0.15$, $\sigma = 20\%$.

# Appendix D. Robustness

To test the robustness of the proposed incentive-based capital requirements, I consider the setting in which issuing equity to insure debt service payments for $x < rD/\delta$ involves proportional costs $\varphi \leq \xi_1$. First, I verify that incentives for taking on tail risk persist in the absence of the asset expansion opportunity. Second, I show that, when asset expansion is feasible, the incentive regulatory threshold triggering asset expansion is still able to eliminate incentives for engaging in tail risk.[30]

## D.1. Moral hazard in the absence of the possibility of asset expansions

Assume that asset expansions are prohibitively costly. Let $x_L$ denote any given liquidation threshold imposed by the regulator and let $x_\varphi = rD/\delta$ be a critical threshold, such that for $x \in [x_L, x_\varphi)$ shareholders incur proportional costs $\varphi$, when issuing equity to service debt.

Bank shareholders would stick to prudent risk management for all $x \geq x_L$, if and only if the following incentive compatibility condition is satisfied for $\forall x \geq x_L$:

$$\lambda(E(x) - \mathbb{1}_{x \geq x_L/\alpha} E(\alpha x)) \geq \Delta\mu x E'(x). \tag{B45}$$

Assume that (B45) holds for $\forall x \geq x_L$. Then, the value of bank equity is driven by the system of ODE:

$$1/2\sigma^2 x^2 E''(x) + (\mu - \Delta\mu) x E'(x) - rE(x) + (1+\varphi)(\delta x - rD) = 0, \quad \forall x \in [x_L, x_\varphi) \tag{B46}$$

$$1/2\sigma^2 x^2 E''(x) + (\mu - \Delta\mu) x E'(x) - rE(x) + \delta x - rD = 0, \quad \forall x > x_\varphi \tag{B47}$$

The general solution of the above system is given as follows:

$$E(x) = C_{11} x^{\beta_1} + C_{12} x^{\beta_2} + (1+\varphi)(\nu\delta x - D), \quad \forall x \in [x_L, x_\varphi) \tag{B48}$$

$$E(x) = C_{22} x^{\beta_2} + \nu\delta x - D, \quad \forall x \geq x_\varphi \tag{B49}$$

where $\nu = (r - \mu + \Delta\mu)^{-1}$ and $\beta_1 > 0$, $\beta_2 < 0$ are the roots of

$$1/2\sigma^2 \beta(\beta - 1) + (\mu - \Delta\mu)\beta = r. \tag{B50}$$

The value-matching and smooth-pasting conditions at $x_\varphi$, together with the boundary condition $E(x_L) = 0$, provide:[31]

$$C_{11} = \frac{\varphi}{\beta_1 - \beta_2} \left( (\beta_2 - 1)\delta\nu x_\varphi - \beta_2 D \right) x_\varphi^{-\beta_1} < 0,$$

$$C_{12} = ((1+\varphi)(D - \delta\nu x_L) - C_{11} x_L^{\beta_1}) x_L^{-\beta_2},$$

[30] This robustness check is performed for the benchmark case. It can be easily adapted to the presence of the internal agency problem by changing $\delta$ to $\delta - w_1^*$.

[31] Given $x_\varphi$ and $\nu$, it can be shown that $C_{11} < 0$.

$$C_{22} = C_{12} + \frac{\varphi}{\beta_1 - \beta_2} \left( (\beta_1 - 1)\delta\nu x_\varphi - \beta_1 D \right) x_\varphi^{-\beta_2}.$$

Then, for $x \in [x_L, x_\varphi)$, bank equity value follows:

$$E(x) = C_{11}(x^{\beta_1} - x^{\beta_2} x_L^{\beta_1 - \beta_2}) + (1+\varphi)(D - \delta\nu x_L)\left(\frac{x}{x_L}\right)^{\beta_2} + (1+\varphi)(\delta\nu x - D). \quad \text{(B51)}$$

The optimal liquidation threshold maximizing equity value, $x_L^\varphi$, will be provided by the first-order condition, which leads to the following equation:

$$(\beta_2 - 1)\delta\nu x_L - \beta_2 D = \frac{\varphi}{1+\varphi}\left((\beta_2 - 1)\delta\nu x_\varphi - \beta_2 D\right)\left(\frac{x_L}{x_\varphi}\right)^{\beta_1}. \quad \text{(B52)}$$

A mandatory liquidation threshold imposed by the regulator cannot be lower than the optimal liquidation threshold chosen by bank shareholders. Thus, consider incentive compatibility condition (B45) for any $x_L \geq x_L^\varphi$. Given the value of equity defined in (B51), for $x \in [x_L, \min\{x_L/\alpha, x_\varphi\})$, the incentive compatibility condition (B45) can be rewritten as follows:

$$\begin{aligned} &C_{11}(x^{\beta_1}(\lambda - \Delta\mu\beta_1) - x^{\beta_2} x_L^{\beta_1-\beta_2}(\lambda - \Delta\mu\beta_2)) + \\ &\quad + (\lambda - \Delta\mu\beta_2)(1+\varphi)(D - \delta\nu x_L)\left(\frac{x}{x_L}\right)^{\beta_2} + (\lambda - \Delta\mu)(1+\varphi)\delta\nu x - (1+\varphi)\lambda D \geq 0. \end{aligned} \quad \text{(B53)}$$

Let $f(x)$ denote the left-hand side of (B53). Then, for $x \to x_L$,

$$\lim_{x \to x_L} f(x) = -\varphi\Delta\mu((\beta_2 - 1)\nu\delta x_\varphi - \beta_2 D)\left(\frac{x_L}{x_\varphi}\right)^{\beta_1} + (1+\varphi)\Delta\mu((\beta_2 - 1)\nu\delta x_L - \beta_2 D). \quad \text{(B54)}$$

Observe that $\lim_{x \to x_L} f(x) > 0$ if and only if

$$(\beta_2 - 1)\nu\delta x_L - \beta_2 D > \frac{\varphi}{1+\varphi}((\beta_2 - 1)\nu\delta x_\varphi - \beta_2 D)\left(\frac{x_L}{x_\varphi}\right)^{\beta_1}. \quad \text{(B55)}$$

Let $f_1(x_L)$ and $f_2(x_L, \varphi)$ denote the left and the right-hand side of (B55), respectively. Since $f_1(x_L)$ and $f_2(x_L, \varphi)$ are monotonically decreasing with $x_L$, $f_1(0) > f_2(0, \varphi)$ and condition (B55) binds for $x_L = x_L^\varphi$, it follows that $f_1(x_L) < f_2(x_L, \varphi)$ for any $x_L > x_L^\varphi$. Therefore, incentive compatibility condition (B45) does not hold in the neighborhood of $\forall x_L \geq x_L^\varphi$. Hence, in the absence of the possibility to comply with capital requirements via asset expansion, the incentives to take on tail risk persist in the presence of equity issuance costs (when equity is issued to ensure debt service) and there is no regulatory threshold that would be able to eliminate them.

## D.2. Incentive effect of asset expansions

Now consider the setting in which bank shareholders have the possibility to comply with minimum capital requirements through asset expansion (realized at reasonable costs) as long as $x \geq x_R$. The objective of this section is to show that, even in the presence of equity issuance costs related to debt service, the regulatory threshold triggering asset expansions is still able to eliminate incentives to take on tail risk, i.e., the following incentive compatibility condition holds for $\forall x \geq x_R$:

$$\lambda(E(x) - \mathbb{1}_{x \geq x_R/\alpha} E(\alpha x)) \geq \Delta\mu x E'(x) \text{ for } \forall x \geq x_R. \tag{B56}$$

For the rest of this section, $x_R$ stands for the minimum incentive-compatible regulatory threshold that makes the incentive constraint (B56) binding at $x = x_R$.

Under the possibility of asset expansions, the value of bank equity will be defined by ODEs (B48) - (B49) solved under the value matching and smooth-pasting conditions at $x_\varphi$, as well as the boundary condition

$$E(x_R) = E(x_R + z x_R) - (1 + \xi_1) z x_R - \xi_0.$$

Two cases might be possible when asset expansion is undertaken: $(1+z)x_R < x_\varphi$ and $(1+z)x_R > x_\varphi$. I perform verification of (B56) for the case $(1+z)x_R < x_\varphi$, which is more plausible given the modest scale of asset expansion revealed by numerical examples.

Consider two auxiliary functions:

$$g_1(z) = -\frac{1 - (1+z)^{\beta_1}}{1 - (1+z)^{\beta_2}} > 0,$$

$$g_2(z) = \frac{\xi_0 + (1 + \xi_1 - (1+\varphi)\delta\nu) z x_R}{1 - (1+z)^{\beta_2}} > 0.$$

Bank equity value is given by:

$$E(x) = C_{11}\left(x^{\beta_1} + g_1(z) x^{\beta_2} x_R^{\beta_1 - \beta_2}\right) - g_2(z)\left(\frac{x}{x_R}\right)^{\beta_2} + (1+\varphi)(\nu\delta x - D), \quad \forall x \in [x_L, x_\varphi), \tag{B57}$$

$$E(x) = C_{22} x^{\beta_2} + \nu\delta x - D, \quad \forall x \geq x_\varphi, \tag{B58}$$

where coefficients $C_{11}$ and $C_{22}$ are defined as follows:

$$C_{11} = \frac{\varphi}{\beta_1 - \beta_2}\left((\beta_2 - 1)\delta\nu x_\varphi - \beta_2 D\right) x_\varphi^{-\beta_1} < 0,$$

$$C_{22} = C_{11} g_1(z) x_R^{\beta_1 - \beta_2} - g_2(z) x_R^{-\beta_2} + \frac{\varphi}{\beta_1 - \beta_2}\left((\beta_1 - 1)\delta\nu x_\varphi - \beta_1 D\right) x_\varphi^{-\beta_2}.$$

Depending on the size of large losses, two alternative cases might be possible: $x_R/\alpha < x_\varphi$ and $x_R/\alpha > x_\varphi$.

**1)** First, consider the setting where $x_R/\alpha < x_\varphi$. The incentive compatibility condition (B56) should be verified for the following regions: $[x_R, x_R/\alpha)$, $[x_R/\alpha, x_\varphi)$ and $[x_\varphi, +\infty)$.

**a)** For $x \in [x_R, x_R/\alpha)$, incentive compatibility condition (B56) is reduced to:

$$\lambda E(x) \geq \Delta\mu x E'(x). \tag{B59}$$

Taking the first derivative of the both parts of (B59) and rearranging the terms yields:

$$E'(x)(\lambda - \Delta\mu) > \Delta\mu x E''(x). \tag{B60}$$

By definition of $x_R$, condition (B59) binds when $x = x_R$. Therefore, to verify that (B59) holds over $[x_R, x_R/\alpha)$, it suffices to show that (B60) is satisfied for $\forall x \in [x_R, x_R/\alpha)$, which is the case if $E''(x) < 0$. Indeed, taking the second derivative of $E(x)$ defined in (B57) yields:

$$E''(x) = \underbrace{C_{11}}_{x<0}\left(\underbrace{\beta_1(\beta_1-1)x^{\beta_1-2} + g_1(z)\beta_2(\beta_2-1)x^{\beta_2-2}x_R^{\beta_1-\beta_2}}_{>0}\right) - \beta_2(\beta_2-1)\frac{g_2(z)}{x^2}\left(\frac{x}{x_R}\right)^{\beta_2} < 0.$$

**b)** For $x \in [x_R/\alpha, x_\varphi)$, condition(B56) can be rewritten as follows:

$$\begin{aligned} &C_{11}\left((\lambda(1-\alpha^{\beta_1}) - \Delta\mu\beta_1)x^{\beta_1} + g_1(z)(\lambda(1-\alpha^{\beta_2}) - \Delta\mu\beta_2)x^{\beta_2}x_R^{\beta_1-\beta_2}\right) - \\ &- g_2(z)(\lambda(1-\alpha^{\beta_2}) - \Delta\mu\beta_2)\left(\frac{x}{x_R}\right)^{\beta_2} + (\lambda(1-\alpha) - \Delta\mu)(1+\varphi)\nu\delta x > 0. \end{aligned} \tag{B61}$$

Observe that $C_{11} < 0$ and $(\lambda(1-\alpha^{\beta_2}) - \Delta\mu\beta_2) < 0$. Then, to ensure (B61), the following condition should be satisfied for $\forall x \in [x_R/\alpha, x_\varphi)$:

$$(\lambda(1-\alpha^{\beta_1}) - \Delta\mu\beta_1)x^{\beta_1} + g_1(z)(\lambda(1-\alpha^{\beta_2}) - \Delta\mu\beta_2)x^{\beta_2}x_R^{\beta_1-\beta_2} < 0. \tag{B62}$$

When $(\lambda(1-\alpha^{\beta_1}) - \Delta\mu\beta_1) < 0$, which is the case when $\alpha \to 0$ and $\lambda$ is relatively high, (B62) always holds. When $(\lambda(1-\alpha^{\beta_1}) - \Delta\mu\beta_1) > 0$, the left-hand side of (B62) is increasing with $x$, so that (B62) holds for $\forall x \in [x_R/\alpha, x_\varphi)$ if and only if

$$g_1(z) > -\left(\frac{\lambda(1-\alpha^{\beta_1}) - \Delta\mu\beta_1}{\lambda(1-\alpha^{\beta_2}) - \Delta\mu\beta_2}\right)\left(\frac{x_\varphi}{x_R}\right)^{\beta_1-\beta_2}. \tag{B63}$$

**Lemma 2** *Let* $g_1(z) = -\frac{1-(1+z)^{\beta_1}}{1-(1+z)^{\beta_2}}$, *where* $\beta_1 > 0$ *and* $\beta_2 < 0$. *Then,* $g_1'(z) > 0$ *for* $\forall z > 0$.

**Proof of Lemma 2.** Taking the first derivative of $g_1(z)$ with respect to $z$ yields $g_1'(z) = \frac{\beta_1(1+z)^{\beta_1-1} - \beta_2(1+z)^{\beta_2-1} - (1+z)^{\beta_1-\beta_2-1}(\beta_1-\beta_2)}{(1-(1+z)^{\beta_2})^2}$. Observe that $g_1'(z) > 0$ if and only if $f_1(z) \equiv \beta_1(1+z)^{-\beta_2} - \beta_2(1+z)^{-\beta_1} - (\beta_1-\beta_2) > 0$. Since $f_1(0) = 0$ and $f_1'(z) > 0$, then $g_1'(z) > 0$ for any $z > 0$.$\square$

Since, by Lemma 2, $g_1(z)$ monotonically increases with $z$, condition (B63) holds when $z$ is not too low.

**c)** Finally, for $x \in [x_\varphi, +\infty)$, condition (B56) can be rewritten as follows:

$$(\lambda(1-\alpha^{\beta_2}) - \Delta\mu\beta_2)C_{22}x^{\beta_2} + (\lambda(1-\alpha) - \Delta\mu)(1+\varphi)\nu\delta x > 0. \tag{B64}$$

The above condition holds for $\forall x \in [x_\varphi, +\infty)$ if and only if $C_{22} < 0$, which is guaranteed by:

$$g_1(z) > -\left(\frac{(\beta_1 - 1)\delta\nu x_\varphi - \beta_1 D}{(\beta_2 - 1)\delta\nu x_\varphi - \beta_2 D}\right)\left(\frac{x_\varphi}{x_R}\right)^{\beta_1 - \beta_2}. \tag{B65}$$

Again, since $g_1'(z) > 0$, condition (B65) holds when $z$ is not too low.

**2)** Now, consider the case where $x_R/\alpha > x_\varphi$. In this case, incentive condition (B56) should be verified for the following regions: $[x_R, x_\varphi)$, $[x_\varphi, x_R/\alpha)$ and $[x_R/\alpha, +\infty)$. It can be shown that, in each region, condition (B56) is ensured by the concavity of $E(x)$.

Therefore, even in the presence of equity issuance costs incurred by shareholders when equity is issued to service interest payments on debt, the incentive regulatory threshold triggering asset expansions is still able to eliminate incentives to take on tail risk.

# Appendix E. Endogenous payout(reinvestment) policy

In this Appendix, I build the extended version of the benchmark-case model that allows for the endogenous payout policy. This additional dimension of the bank shareholders' policy is introduced by assuming that shareholders have a possibility to reinvest a fraction $\Lambda x_t dt$ of the asset cash-flow,[32] where $\Lambda \in [0, \delta]$, without incurring any fixed asset adjustment costs. However, reinvestment might involve some proportional deadweight costs, which is captured by the fact that reinvesting $\Lambda x_t dt$ would generate an instantaneous increase $\Lambda(1-\kappa)x_t dt$ in the value of assets, where $\kappa \in [0, 1)$.

There are two main questions to be addressed in this framework: (i) what are the implications of the endogenous payout(reinvestment) policy[33] on the design of the incentive-based capital regulation? (ii) whether constraining payouts to shareholders would reduce the need for tighter capital regulation?[34]

## E.1. Incentive-based capital requirements under the endogenous payout(reinvestment) policy

The design of the incentive-based regulatory threshold in the extended version of the model resembles the one presented in Section 4. The sole distinction refers to the fact that now the regulator should take into account the optimal reinvestment policy of bank shareholders when selecting the optimal level of incentive-based capital requirements.

[32] Making the reinvestment rate proportional to the bank asset value helps preserve the Geometric Brownian Motion (GBM) properties of the process describing the dynamics of the bank asset value. The similar approach to dealing with reinvestment is used by Diamond and He (2014).

[33] For the rest of the section, the terms "payout policy" and "reinvestment policy" are used interchangeably.

[34] After the recent financial crisis, a number of academic papers (see e.g. Admati, DeMarzo, Hellwig and Pfleiderer (2011), Acharya, Gujral, Kulkarni and Shin (2011), among others) advocated for imposing restrictions on dividend payments for the financially distressed banks. Under Basel III, restrictions on dividend payments were introduced for the banks that fail to maintain capital conservation buffers.

To define the optimal reinvestment strategy that would be chosen by bank shareholders, assume that the regulatory threshold $x_R$ is set in such a way so as to induce bank shareholders to stick to prudent risk management. Bank shareholders choose the optimal reinvestment strategy that would maximize the value of their claim. Let $i_t \in \{0,1\}$ denote a binary control variable such that $i_t = 1$ reflects the shareholders' decision to reinvest the fraction $\Lambda x_t dt$ of the asset cash-flow. The optimal reinvestment policy is defined by the solution to the following Bellman equation:

$$rE(x) = \max_{i\in\{0,1\}} \left\{\frac{1}{2}\sigma^2 x^2 E''(x) + (\mu - \Delta\mu + i\Lambda(1-\kappa))xE'(x) + (\delta - i\Lambda)x - rD\right\}. \quad \text{(B66)}$$

Under the conjecture that $E''(x) < 0$ (this is verified ex-post), reinvestment is optimal in the region $[x_R, \tilde{x}]$, where the reinvestment threshold $\tilde{x}$ is implicitly given by

$$E'(\tilde{x}) = 1/(1-\kappa). \quad \text{(B67)}$$

Notice that, when $\kappa$ is relatively high, reinvestment will be suboptimal and the model will collapse to the case examined in the Section 4.

The further analysis is conducted under the assumption that the deadweight costs of reinvestment, $\kappa$, are relatively low, so that there exists $\tilde{x} > x_R$. Solving the ODE (B66), while allowing for the optimal reinvestment strategy and the set of boundary, smooth-pasting and value-matching conditions, yields the following expressions for the value of equity in the region $[\tilde{x}, +\infty)$[35]

$$E(x) = \nu\delta x - D - \tilde{\Omega}(x_R, z, \tilde{x})x^{\beta_2}, \quad \text{(B68)}$$

where

$$\tilde{\Omega}(x_R, z, \tilde{x}) = \frac{h_1(x_R, z, \tilde{x}) + \tilde{\delta}\tilde{\nu}zx_R - (1+\xi_1)zx_R - \xi_0}{h_2(x_R, z, \tilde{x})}, \quad \text{(B69)}$$

$$h_1(x_R, z, \tilde{x}) = \frac{(\delta\nu - \tilde{\delta}\tilde{\nu})\tilde{x}}{\tilde{\beta}_1 - \tilde{\beta}_2}\Big[(\tilde{\beta}_1 - 1)\Big(\frac{x_R}{\tilde{x}}\Big)^{\tilde{\beta}_2}\Big((1+z)^{\tilde{\beta}_2} - 1\Big) - (\tilde{\beta}_2 - 1)\Big(\frac{x_R}{\tilde{x}}\Big)^{\tilde{\beta}_1}\Big((1+z)^{\tilde{\beta}_1} - 1\Big)\Big], \quad \text{(B70)}$$

$$h_2(x_R, z, \tilde{x}) = \frac{\tilde{x}^{\beta_2}}{\tilde{\beta}_1 - \tilde{\beta}_2}\Big[(\tilde{\beta}_1 - \beta_2)\Big(\frac{x_R}{\tilde{x}}\Big)^{\tilde{\beta}_2}\Big((1+z)^{\tilde{\beta}_2} - 1\Big) - (\tilde{\beta}_2 - \beta_2)\Big(\frac{x_R}{\tilde{x}}\Big)^{\tilde{\beta}_1}\Big((1+z)^{\tilde{\beta}_1} - 1\Big)\Big], \quad \text{(B71)}$$

with $\tilde{\delta} = \delta - \Lambda$, $\tilde{\nu} = (r - \mu - \Lambda(1-\kappa) + \Delta\mu)^{-1}$, and $\tilde{\beta}_1 > 0$, $\tilde{\beta}_2 < 0$ are the roots of the characteristic equation corresponding to ODE (B66) in the region $[x_R, \tilde{x}]$.

In the region $[x_R, \tilde{x}]$, equity value is defined as follows:

$$E(x) = \tilde{\delta}\tilde{\nu}x - D - \tilde{\Omega}(x_R, z, \tilde{x})\chi_1(x, \tilde{x}) + \chi_2(x, \tilde{x}), \quad \text{(B72)}$$

where

$$\chi_1(x, \tilde{x}) = \frac{\tilde{x}^{\beta_2}}{\tilde{\beta}_1 - \tilde{\beta}_2}\Big[(\tilde{\beta}_1 - \beta_2)\Big(\frac{x}{\tilde{x}}\Big)^{\tilde{\beta}_2} - (\tilde{\beta}_2 - \beta_2)\Big(\frac{x}{\tilde{x}}\Big)^{\tilde{\beta}_1}\Big], \quad \text{(B73)}$$

[35]It can be shown that $\tilde{\Omega}(x_R, z, \tilde{x}) > 0$, which immediately yields $E''(x) < 0$.

$$\chi_2(x,\tilde{x}) = \frac{(\delta\nu - \tilde{\delta}\tilde{\nu})\tilde{x}}{\tilde{\beta}_1 - \tilde{\beta}_2}\Big[(\tilde{\beta}_1 - 1)\Big(\frac{x}{\tilde{x}}\Big)^{\tilde{\beta}_2} - (\tilde{\beta}_2 - 1)\Big(\frac{x}{\tilde{x}}\Big)^{\tilde{\beta}_1}\Big]. \tag{B74}$$

To avoid the time consistency problem, the regulatory threshold should be selected so as to maximize equity value in the region $[\tilde{x}, +\infty)$. Under this consideration, the regulatory problem can be stated as follows:

$$\min_{x_R>0, z>0} \quad \tilde{\Omega}(x_R, z, \tilde{x}) \qquad \text{s.t.} \tag{B75}$$

$$\lambda(E(x) - \mathbb{1}_{x \geq x_R/\alpha} E(\alpha x)) \geq \Delta\mu x E'(x) \quad \text{for } \forall x \geq x_R, \tag{B76}$$

where $\tilde{x}$ satisfies (B67) and $E(x)$ is defined by (B68) and (B72).

As in the case of the rigid payout policy discussed in Section 4, an appropriate candidate for the optimal incentive-based regulatory threshold would be $x_R$ that makes the incentive-constraint (B76) binding at $x = x_R$. However, in the current setting, one has to solve simultaneously for the optimal incentive-based regulatory threshold and the optimal reinvestment threshold, so that proceeding with the analytical verification of the incentive constraint is not possible. Given that analytic approach to the problem solution turns out to be sterile, I solve the whole problem numerically in order to get more insights into the interplay between reinvestment decisions and incentive-based capital regulation.[36]

Table 1 reports the optimal incentive-based regulatory threshold, $x_R^B(\tilde{x})$, and the optimal reinvestment threshold, $\tilde{x}$, computed for the different levels of reinvestment rate $\Lambda$ and deadweight costs $\kappa$. These numerical outcomes highlight three important results clarifying the interaction between the endogenous reinvestment policy and incentive-based capital regulation. First, for the same level of deadweight costs, the optimal incentive-based regulatory threshold declines with the reinvestment rate $\Lambda$, since reinvestment at a higher rate alleviates the moral hazard problem. Second, for a given level of reinvestment rate $\Lambda$, higher deadweight costs of reinvestment, $\kappa$, would raise the need for tighter incentive-based capital regulation. This result can be easily understood in the light of the fact that taking on tail risk can be seen as an alternative way of increasing the expected asset growth rate. Higher deadweight costs of reinvestment would make this alternative more attractive to bank shareholders, so that this effect must be offset by stricter capital requirements. Finally, one can observe that reinvestment is optimal only in the close neighborhood of the regulatory threshold. This confirms the intuition that the shareholders' willingness to reinvest is driven solely by precautionary motives.

## E.2. Payout restrictions and risk-taking incentives

The extended version of the model offers an opportunity to investigate the impact of payout restrictions on the bank's incentives to take on tail risk. Again, to preserve the GBM properties of the process driving the dynamics of the bank asset value, I model payout restrictions as the regulatory requirement to reinvest the fraction $\Lambda$ of the asset cash-flow when the bank asset value is below some exogenous reinvestment threshold $\overline{x} > rD/\delta$. Clearly, such a specification is not ideal for properly dealing with payout restrictions: it implies only partial reductions of dividend payments in the region $[rD/\tilde{\delta}, \overline{x}]$

[36]The numerical analysis realized in this section is not intended to provide any quantitative predictions, but rather serves for the illustration of general patterns.

Table 1: Regulatory and reinvestment thresholds

| | $\kappa = 0$ | | $\kappa = 0.02$ | | $\kappa = 0.04$ | |
|---|---|---|---|---|---|---|
| | $x_R^B(\tilde{x})$ | $\tilde{x}$ | $x_R^B(\tilde{x})$ | $\tilde{x}$ | $x_R^B(\tilde{x})$ | $\tilde{x}$ |
| $\Lambda = 0$ | 1.1912 | – | 1.1912 | – | 1.1912 | – |
| $\Lambda = 0.005$ | 1.1896 | 1.6146 | 1.1907 | 1.4097 | 1.1912 | 1.2671 |
| $\Lambda = 0.01$ | 1.1880 | 1.6007 | 1.1901 | 1.4056 | 1.1911 | 1.2666 |
| $\Lambda = 0.019$ | 1.1855 | 1.5781 | 1.1892 | 1.3987 | 1.1910 | 1.2659 |

Table 1 reports the values of the optimal incentive-based regulatory thresholds and the associated reinvestment thresholds computed for different levels of reinvestment rate and deadweight costs of reinvestment. The input parameter values are: $D = 1$, $r = 4\%$, $\sigma = 20\%$, $\mu = 2.5\%$, $\Delta\mu = 0.5\%$, $\delta = 1.9\%$, $\alpha = 0.9$, $\lambda = 0.15$, $\xi_0 = 0.0001$, $\xi_1 = 0.05$.

and requires issuing more equity to maintain the continuity of debt service in the region $[x_R, rD/\tilde{\delta}]$.[37] Nevertheless, even such a rough way of modeling payout restrictions helps get some insights into the potential impact of this regulatory measure on the risk-taking incentives of bank shareholders. To illustrate this impact, I numerically compute the optimal incentive-based regulatory threshold, $x_R^B(\overline{x})$, for a wide range of the mandatory reinvestment thresholds $\overline{x}$.[38]

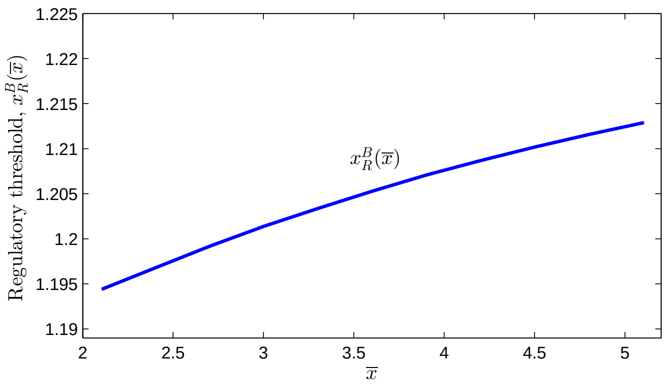



Figure 1: Payout restrictions on the incentive-based capital regulation

This figure depicts the optimal incentive-based regulatory threshold as a function of the mandatory reinvestment threshold $\overline{x}$. The input parameter values are: $\Lambda = 0.01$, $D = 1$, $r = 4\%$, $\sigma = 20\%$, $\mu = 2.5\%$, $\Delta\mu = 0.5\%$, $\delta = 1.9\%$, $\alpha = 0.9$, $\lambda = 0.15$, $\xi_0 = 0.0001$, $\xi_1 = 0.05$.

Figure 1 shows that the optimal incentive-based regulatory threshold $x_R^B(\overline{x})$ is increasing with $\overline{x}$. This relation can easily be understood in the light of the fact that imposing payout restrictions would induce a deviation from the optimal payout policy of bank shareholders and, thereby, would reduce the value of shareholder's claim, making

[37] An inventory model, in which the payout policy is contingent on the level of liquid reserves (see e.g. Decamps, Mariotti, Rochet, and Villeneuve (2011) or Hugonnier and Morellec (2014)), might be better suited to this kind of analysis.

[38] The computation implies solving the regulatory problem (B75) - (B76), in which the optimal reinvestment threshold $\tilde{x}$ is substituted by the exogenous reinvestment threshold $\overline{x}$.

shareholders more reluctant to inject capital into the bank upon reaching the regulatory threshold. Yet, the whole incentive effect of capital regulation in this paper is anchored to the shareholders' willingness to keep the bank operating upon reaching the regulatory threshold. In such a context, the upward adjustments of the optimal incentive-based regulatory threshold are needed in order to offset the adverse effect of payout restrictions on risk-taking incentives.

# References

Admati, A., DeMarzo, P., Hellwig, M., and P. Pfleiderer, 2011. Fallacies, Irrelevant Facts, and Myths in the Discussion of Capital Regulation: Why Bank Equity is Not Expensive. Mimeo.

Admati, A., Conti-Brown, P., and P. Pfleiderer, 2012. Liability Holding Companies. UCLA Law Review 59, 852 - 914.

Acharya, V., Pagano, M., and P. Volpin, 2013. Seeking Alpha: Excess Risk Taking and Competition for Managerial Talent. NBER Working Paper 18891.

Acharya, V., Cooley, T., Richardson, M., and I. Walter, 2010. Manufacturing Tail Risk: A Perspective on the Financial Crisis of 2007-09. Foundations and Trends in Finance 4, 247-325.

Acharya, V., Gujral, I., Kulkarni, N., and H. Shin, 2011. Dividends and Bank Capital in the Financial Crisis of 2007-2009. Working paper, NYU-Stern and Princeton University.

Bebchuk, L., and H. Spamann, 2010. Regulating Bankers Pay. Georgetown Law Journal 98(2), 247-287.

Bebchuk, L., Cohen, A., and H. Spamann, 2010. The wages of failure: Executive compensation at Bear Stearns and Lehman 2000-2008. Yale Journal on Regulation 27, 257 - 282.

Bebchuk, L., and J. Fried, 2004. Pay without performance: The unfulfilled promise of executive compensation. Harvard University Press, Cambridge.

Bhagat, S., and B. Bolton, 2013. Bank Executive Compensation and Capital Requirements Reform. Available at SSRN: http://ssrn.com/abstract=1781318.

Biais, B., Mariotti, T., Rochet, J.-C., and S. Villeneuve, 2010. Large risk, limited liability, and dynamic moral hazard. Econometrica 78, 73 - 118.

Bolton, P., Mehran, H., and J. Shapiro, 2013. Executive Compensation and Risk Taking. Federal Reserve Bank of New York, Staff Report no. 456. Available at SSRN: http://ssrn.com/abstract=1635349.

Bhattacharya, S., Plank, M., Strobl, G., and J. Zechner, 2002. Bank capital regulation with random audits. Journal of economic dynamics and control 26, 1301-1321.

Bris, A., and S. Cantale, 2004. Bank capital requirements and managerial self-interest. The Quarterly Review of Economics and Finance 44, 77 - 101.

Chen, N., Glasserman, P., Nouri, B., and M. Pelger, 2013. CoCos, Bail-In, and Tail Risk. Office of Financial Research Working Paper No. 0004. Available at SSRN: http://ssrn.com/abstract=1781318.

Chen, C., Steiner, T., and A.M. Whyte, 2006. Does stock option-based executive compensation induce risk-taking? An analysis of the banking industry. Journal of Banking and Finance 30, 915-945.

Cheng, I.-H., Hong, H., and J. A. Scheinkman, 2014. YesterdayŠs Heroes: Compensation and Risk at Financial Firms. Journal of Finance, forthcoming.

Decamps, J.-P., Rochet, J.-C., and B. Roger, 2004. The Three Pillars of Basel II: Optimizing the Mix. Journal of Financial Intermediation 13, 132-155.

Decamps, J.-P., Mariotti T., Rochet, J.-C., and S. Villeneuve, 2011. Free Cash Flow, Issuance Costs, and Stock Prices. Journal of Finance 66, 1501-1544.

DeMarzo, P. M., Livdan, D., and A. Tchistyi, 2013. Risking Other People's Money: Gambling, Limited Liability, and Optimal Incentives. Mimeo. Available at SSRN: http://ssrn.com/abstract=2324879.

DeYoung, R., Peng, E.Y., and M. Yan, 2013. Executive Compensation and Policy Choices at U.S. Commercial Banks. Journal of Financial and Quantitative Analysis 48, 165 - 196.

Diamond, D. W., and Z. He, 2014. A Theory of Debt Maturity: The Long and Short of Debt Overhang. Journal of Finance 69, 719 - 762.

Fahlenbrach, R., and R. M. Stulz, 2011. Bank CEO Incentives and the Credit Crisis. Journal of Financial Economics 99, 11-26.

Gabaix, X., and A. Landier, 2008. Why has CEO Pay Increased So Much? Quarterly Journal of Economics 123, 49 - 100.

He, Z., 2009. Optimal Executive Compensation when Firm Size Follows Geometric Brownian Motion. Review of Financial Studies 22, 859 - 892.

Hugonnier, J., and E. Morellec, 2014. Bank Capital, Liquid Reserves, and Insolvency Risk. EPFL Working Paper.

Koziol, C., and J. Lawrenz, 2012. Contingent convertibles. Solving or seeding the next banking crisis? Journal of Banking and Finance 36, 90 - 104.

Leland, H. E., 1994. Corporate debt value, bond covenants, and optimal capital structure. Journal of Finance 49, 1213 - 1252.

Laevin L., and R. Levine, 2009. Bank governance, regulation and risk taking. Journal of Financial Economics 93, 259 - 275.

Laffont, J., and D. Martimort, 2002. The Theory of Incentives: The Principal-Agent Model. Princeton University Press.

Makarov, I., and G. Plantin, 2013. Rewarding Trading Skills Without Inducing Gambling. Journal of Finance, forthcoming.

Mehran, H., and J. V. Rosenberg, 2007. The Effect of Employee Stock Options on Bank Investment Choice, Borrowing, and Capital. Federal Reserve Bank of NewYork Staff Report No. 305. Available at SSRN: http://ssrn.com/abstract=1022972.

Milne, A., and A. E. Whalley, 2001. Bank Capital Regulation and Incentives for Risk-Taking. Cass Business School Research Paper. Available at SSRN: http://ssrn.com/abstract=299319.

Ofek, E., and D. Yermack, 2000. Taking Stock: Equity-Based Compensation and the Evolution of Managerial Ownership, Journal of Finance 55, 1367-1384.

Pathan, S., 2009. Strong boards, CEO power and bank risk-taking. Journal of Banking and Finance 33, 1340 - 1350.

Pennacchi, G., 2010. A Structural Model of Contingent Bank Capital. FRB of Cleveland Working Paper No. 10-04. Available at SSRN: http://ssrn.com/abstract=1595080.

Perotti, E., Ratnovski, L., and R. Vlahu, 2011. Capital Regulation and Tail Risk. International Journal of Central Banking 7, pages 123 - 163.

Peura, S., and J. Keppo, 2006. Optimal bank capital with costly recapitalisation. The Journal of Business 79, 2163 - 2201.

Rochet, J.-C., and S. Villeneuve, 2011. Liquidity management and corporate demand for hedging and insurance. Journal of Financial Intermediation 20, 303 - 323.

Rajan, R., 2008. Bankers' Pay Is Deeply Flawed, Financial Times, January 9.

Sannikov, Y., 2008. A Continuous-Time Version of the Principal-Agent Problem. The Review of Economic Studies 75, 957-984.